Section E : Radioactivity

I Radiation and Radioactivity

(Revision Course)

PHYSICS

CW Sham

& His Team

College BEACON
遵理學校

Diploma of Secondary Education

Section E : Radioactivity

I Radiation and Radioactivity

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Section E : Radioactivity I – Radiation & Radioactivity

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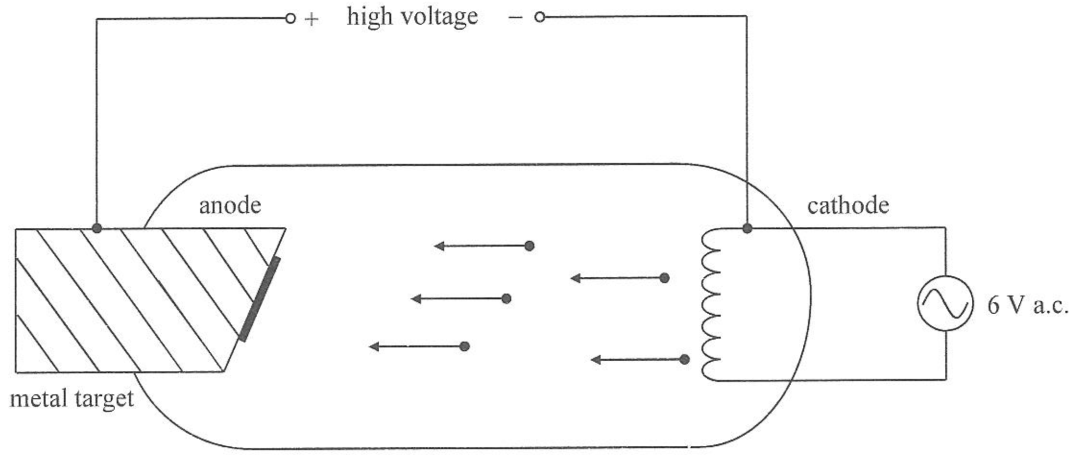
1. X-rays (X-射線)

(i) Production of X-rays (X-射線的產生)

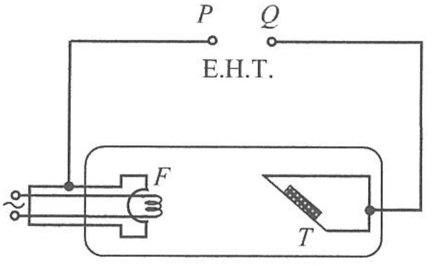


- **X-ray was discovered by Rontgen** (倫琴) **in 1895. He won the Nobel Prize in 1901.**
- **A high voltage** (EHT) **is applied to a vacuum tube** (真空管). **The positive terminal is called anode** (陽極) **and the negative terminal is called cathode** (陰極).
- **When the cathode is heated by a low voltage supply** (6 V), **a beam of high-speed electrons** (cathode ray) **is produced by thermionic emission.**
- **X-ray was produced when cathode ray hits the metal target at the anode.**

(ii) Properties of X-rays (X-射線的特性)

- **X-ray is a type of electromagnetic waves** (電磁波) **with wavelength of about** 10^{-10} m.
  ① X-ray is a transverse wave.
  ② X-ray can travel in vacuum or air with a speed equal to that of light.
  ③ X-ray does not carry charge, thus it would not be deflected by electric field or magnetic field.
- **X-ray is an ionizing radiation** (致電離輻射). **Ionizing radiations have energy high enough to kick out electrons from atoms to become ions** (電離子), **thus they are very dangerous.**
- **X-rays have high penetrating power.**
- **X-rays can detected by a film.**
- **Over exposure to X-rays is dangerous and causes severe damage to body cells.**

Example :
{2012}



The figure shows a schematic diagram of an X-ray tube in which the filament F and the metal target T are connected to terminals P and Q of an E.H.T. Which statement is correct ?

A. P is the positive terminal and X-rays are emitted from T.

B. P is the positive terminal and X-rays are emitted from F.

C. Q is the positive terminal and X-rays are emitted from T.

D. Q is the positive terminal and X-rays are emitted from F.

(iii) Applications of X-rays (X-射線的應用)

① Medical use

- ✻ By taking X-ray pictures of the chest, doctor can diagnose lung disease.
- ✻ CT scanner uses X-rays to take images of the interior of the human bodies.

② Industry

- ✻ High frequency X-rays that can penetrate metal are used.
- ✻ X-rays are used to detect hidden weapons in luggage at airport.
- ✻ X-rays can also be used to inspect welded joints between metal plates.

Example : Which of the following statements about X-rays is/are correct ?

(1) X-rays consist of fast moving electrons.

(2) X-rays are produced when a heavy metal target is struck by fast moving electrons.

(3) In the production of X-rays, the speed of the X-rays depends on the speed of the electrons hitting the metal target

(4) X-rays can blacken photographic films.

(5) X-rays can be used to detect weapons hidden in luggage.

2. Properties of Nuclear Radiation（核輻射的特性）

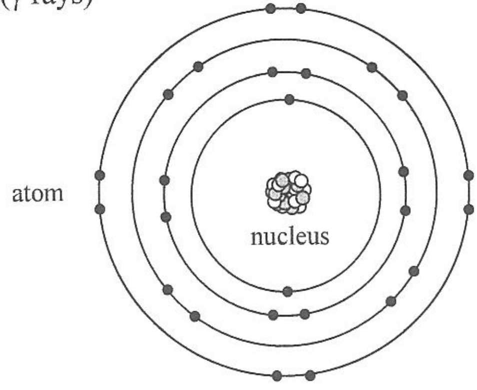
(i) Types of nuclear radiations（核輻射的分類）

✧ **Nuclear radiations consist of :**

① alpha radiation (α particles)

② beta radiation (β particles)

③ gamma radiation (γ rays)



✧ **All the radioactive radiations come from the nucleus of atoms and thus carry large energy.**

(ii) Use of electron-volt in atomic scale（在原子尺度下使用電子伏特）

✧ **The SI unit of energy is joule** (J).

✧ **Electron-volt**（電子伏特）**is a convenient unit of energy used in atomic scale.**

✧ **Conversion between** eV **and** J **:** { $e = 1.60 \times 10^{-19}$ C }

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J} \qquad 1 \text{ J} = \frac{1}{1.6 \times 10^{-19}} \text{ eV}$$

✧ **Typical order of energy of a radioactive particle** (α, β or γ) **is** MeV.

$$1 \text{ MeV} = 1 \times 10^{6} \times 1.6 \times 10^{-19} \text{ J}$$

Example : Given that the mass of an alpha particle is 6.64×10^{-27} kg. An alpha particle has energy of 5 MeV. Calculate the speed of the alpha particle with energy.

By $KE = \frac{1}{2} m v^2$

$\therefore\ (5 \times 10^{6} \times 1.6 \times 10^{-19}) = \frac{1}{2} \times (6.64 \times 10^{-27})\, v^2$

$\therefore\ v =$ ____________________ m s^{-1}

(iii) Sources of radiation (放射源)

✧ **All the nuclear radiations are emitted from radioactive sources.**

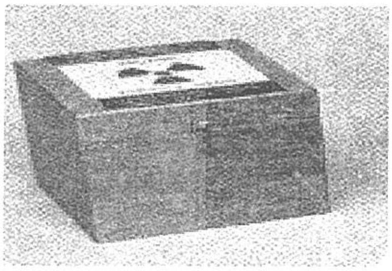
✧ **In school laboratory, there are 4 types of radioactive sources :**

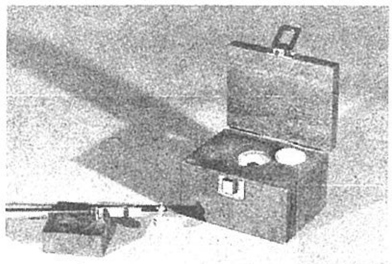
① Amercium (鋂) emitting α radiation

② Strontium (鍶) emitting β radiation

③ Cobalt (鈷) emitting γ radiation

④ Radium (鐳) emitting α, β and γ radiation





(iv) Natures of the 3 types of radiation (三種核輻射的本質)

	alpha particle	**beta particle**	**gamma rays**
Nature (性質)	a helium nucleus	a fast moving electron	electromagnetic wave
Symbol (符號)	α	β	γ
Mass (質量)	$\sim 4u$	$\sim \frac{1}{1800}u$	0
Charge (電荷)	2(+)	1(−)	neutral
Speed (速度)	$\sim 0.1c$	$\sim 0.9c$	c

✧ **Mass in descending order** (由大至小) : $\alpha > \beta > \gamma$

✧ **Speed in ascending order** (由小至大) : $\alpha < \beta < \gamma$

(v) Range in air（空氣中的射程）

① **Alpha particles**

* ✻ very short range in air α
* ✻ typical range : a few centimetres (5 cm)

② **Beta particles**

* ✻ medium range in air β
* ✻ typical range : a few metres (5 m)

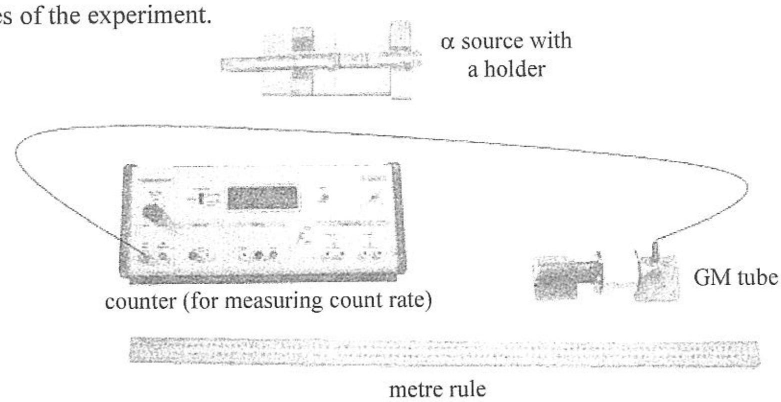
③ **Gamma radiation**

* ✻ very long range in air γ
* ✻ typical range : hundreds of metres (500 m)

✧ **Ascending order of the range in air :** $\alpha < \beta < \gamma$ 相差100倍.

✧ **In vacuum, α, β and γ have infinite ranges.**

Example : In a physics lesson, a teacher uses the apparatus shown in Figure 13 to find the range of α particles in the air. Describe the procedures of the experiment.
(2007) (4 marks)



Place the α source close to and facing the GM tube. [1]

Increase their separation gradually and observe the count rate reading. [1]

Mark the point for the rapid drop in count rate. [1]

Measure the distance between α source and the GM tube with the metre rule to give the range. [1]

Example : The speeds of X-rays, γ rays and β rays in air are denoted by v_X, v_γ and v_β respectively. Which of the following is true ?
(1986)

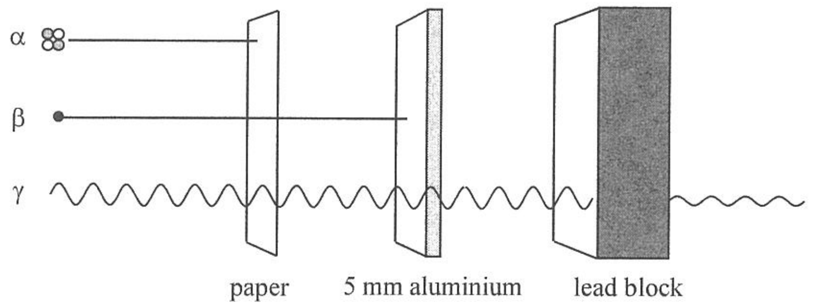
A. $v_X > v_\gamma > v_\beta$

B. $v_X < v_\gamma < v_\beta$

C. $v_X = v_\gamma = v_\beta$

D. $v_X = v_\gamma > v_\beta$

(vi) Penetrating power (貫穿能力)



① **Alpha particles**

- stopped and absorbed by a piece of paper
- stopped and absorbed by the skin of human body

② **Beta particles**

- partly absorbed by 1 mm aluminium sheet
- totally stopped and absorbed by an aluminium block with thickness of about 5 mm
- stopped and absorbed by the muscle of the human body

③ **Gamma radiation**

- can be partly absorbed by a lead block
- intensity (強度) of the gamma radiation decreases as the thickness of the lead increases
- can almost completely penetrate through the human body
- note that gamma radiation can **never** be totally absorbed

✧ **Ascending order of the penetrating power :** $\alpha < \beta < \gamma$

Example : (a) A radioactive source emitting alpha particles is stored inside a thin metal container. Explain whether it is safe or not to be handled by the bare hands.

It is safe **since the penetrating power of alpha particles is so** weak **that they** cannot pass **through the metal.**

(b) A radioactive source emitting gamma radiation is stored inside a lead castle made of thick lead blocks. Explain whether it is safe or not to be handled by the bare hands.

It is not safe **since the penetrating power of gamma radiations is so** strong **that they cannot be completely** blocked **by the lead.**

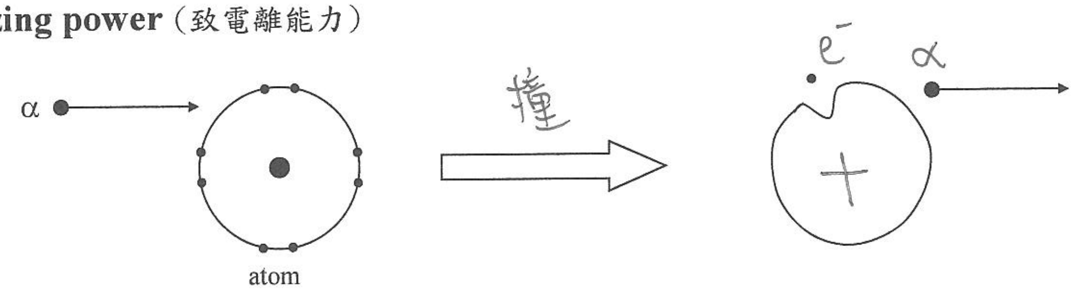
Example : (2001) The speed of gamma rays in air is much higher than that of visible light.

Same γ (F)

Gamma rays can pass through aluminium sheets of a few mm thick but visible light cannot.

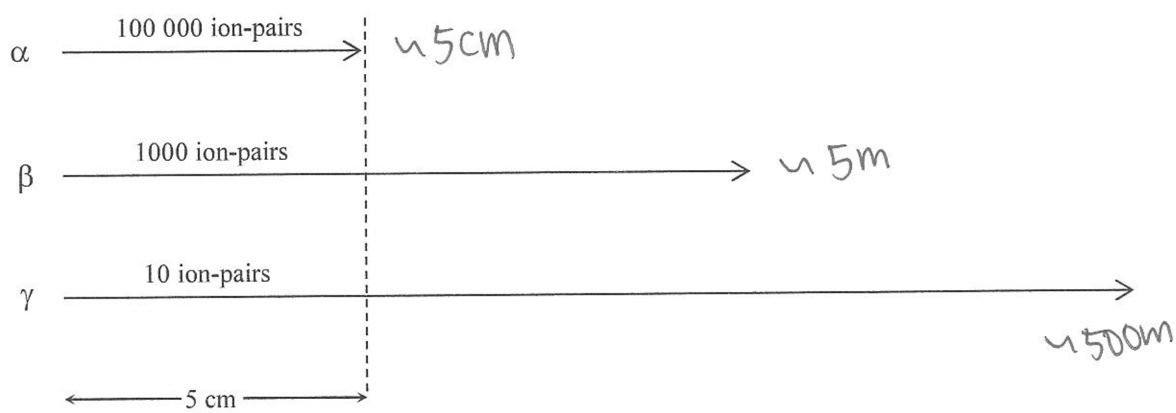
(T)

(vii) Ionizing power（致電離能力）



- When a radioactive particle passes through air, the particle would collide with the air molecules and knock out an electron from air molecules to produce ion-pairs（離子對）. This is called ionization of air.

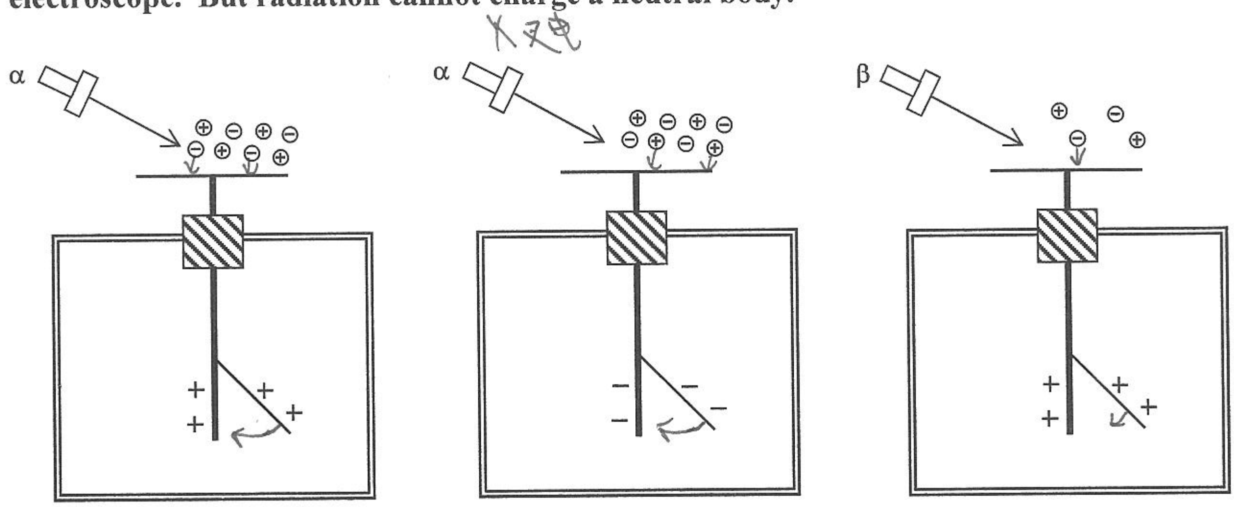
- The ionizing power is the number of ion-pairs produced in each centimetre.



- Ionizing power of radiation in descending order : α > β > γ

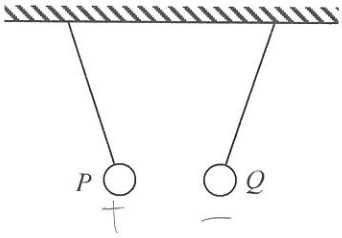
- Penetrating power is related to the ionizing power. The greater the ionizing power, the less is the penetrating power.

- Radiation can 放电 discharge a charged body (no matter it is positive or negative) such as an electroscope. But radiation cannot charge a neutral body.



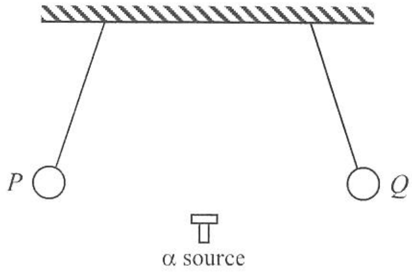
- The rate of discharge by radiation is shown by the rate of fall of the leaf in the electroscope. Rate of fall of the gold leaf : α > β > γ

Example :
(2010)

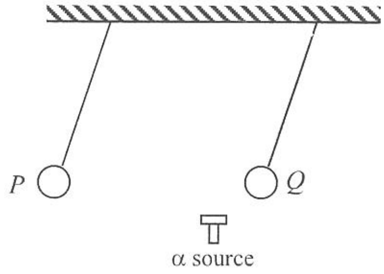


In the figure above, two charged metal balls *P* and *Q* are hung by insulating threads. *P* is positively charged while *Q* is negatively charged. An α source is put near the balls without touching them. Which of the following figures shows the situation after a period of time ?

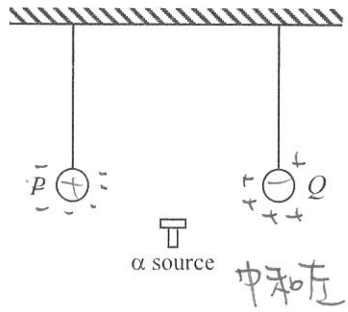
A.



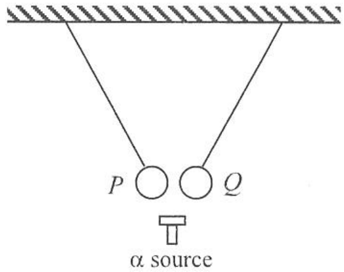
B.



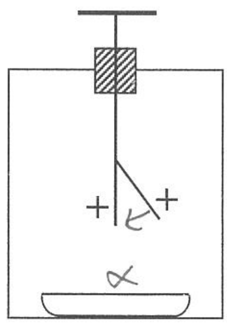
C.



D.



Example :
[1985]



A dish containing a strong α-source is placed inside a gold leaf electroscope containing dry air. If the gold-leaf is originally positively charged, what will happen to it after a few minutes ?

A. It will increase in divergence.

B. It will increase in divergence and then decrease.

C. It will collapse.

D. It will collapse and then re-diverge.

Example : Which of the following statements about α and β particles is/are correct ?

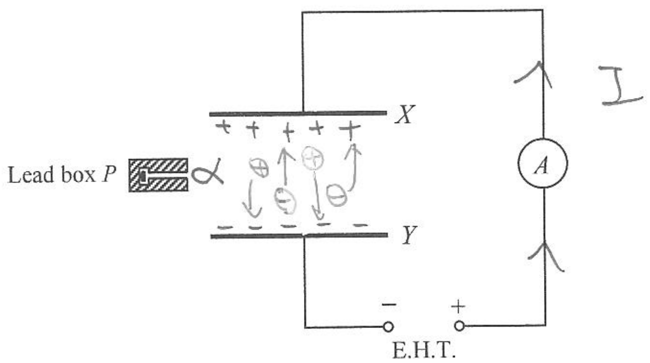
{PP} ✓(1) The mass of an α particle is greater than that of a β particle.

✗(2) α particles have a stronger penetrating power than β particles.

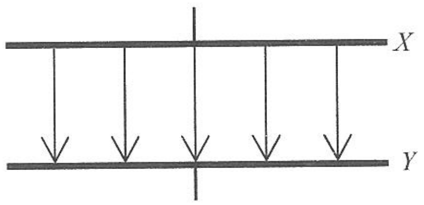
(3) An α source can discharge a positively charged metal sphere nearby.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

Example : Two metal plates X and Y are connected to a sensitive ammeter and an extra high tension supply (E.H.T.). A lead box P
(1991) is placed near the metal plates as shown in the below figure.



(a) Sketch the electric field pattern between X and Y. The direction of the field should be shown. (2 marks)



< Direction of electric field lines is downwards > [1]

< The electric field lines are parallel and evenly spaced > [1]

(b) If a radioactive source emitting α particles is placed in P, the ammeter shows that a current is flowing. Explain why there is a current. (2 marks)

Air molecules are ionized by α particles. [1]

The ions then move to the metal plates to conduct a current. [1]

(c) Explain what happens to the ammeter reading if the source in (ii) is replaced by one emitting γ rays ? (2 marks)

The ammeter reading decreases ; (OR becomes zero) [1]

since the ionization power of γ radiation is very weak. [1]

3. Detection of radiation (探測輻射)

(i) Photographic film (感光底片)

✧ All the 3 types of nuclear radiation can be detected by a photographic film.

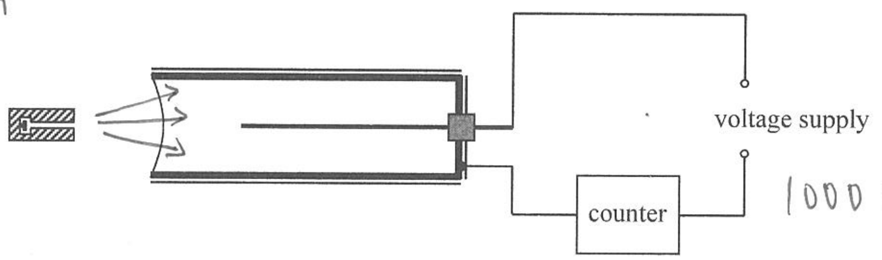
✧ When the film is exposed to radiation, the film would be blackened.

✧ The degree of blackening indicates the intensity of the radiation. The more the blackening of the film, the higher is the intensity of the radiation.

(ii) GM tube (Geiger-Muller tube) (蓋革-彌勒管)

1 min

500 α
200 β
300 γ



1000 c.p.m

✧ A GM tube can be connected to a counter to form a GM counter (蓋革-彌勒計數器).

✧ The measured value is called the count rate (計數率).

✧ Unit of count rate is counts per minute (c.p.m.) or counts per second.

✧ All the 3 types of radioactive radiation can be detected by a GM counter.

✧ The count rate includes the total counts of α, β and γ, irrespective of their ionizing power.

✧ Use of the GM counter to measure the range of α in air :

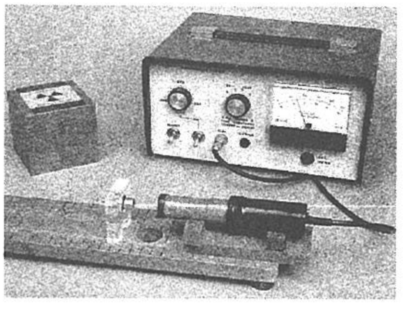
① Place the GM counter in line of the alpha source.

② Start with the GM counter close to the alpha source.

③ Record the reading of the counter.

④ Move the source gradually away from the GM tube.

⑤ At a point that the count rate suddenly drops, measure the distance between the source and the GM tube with a ruler. This gives the range of the alpha source.



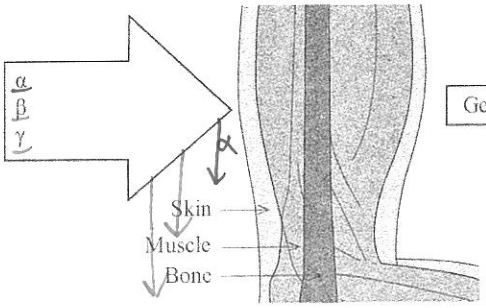
✧ Use of the GM counter to demonstrate the random nature of radiation (輻射的隨機性) :

Time / hour	0	1	2	3	4
Count rate / counts per minute	260	262	258	263	257

✱ The slight fluctuation of the count rate is due to the random nature of radiation.

random process

Example :



The diagram shows radiation from a radium source approaching a person's arm. A Geiger-Muller tube on the other side of the arm detects radiation. The radiation detected is substantially less than would be detected without the arm in position. This is because the

✗ (1) bone is absorbing α-radiation.
✗ (2) ~~muscle~~ skin is absorbing α-radiation.
✓ (3) muscle is absorbing β-radiation.
✗ (4) skin is absorbing γ-radiation.

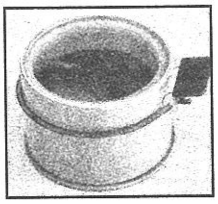
Example : Different absorbers are placed in turn between a radioactive source and a Geiger-Muller tube. Three readings are taken
(2004) for each absorber. The following data are obtained :

Absorber	Count rate / s^{-1}			
–	200	205	198	
Paper	197	202	206	no α
5 mm aluminium	112	108	111	β
25 mm lead	60	62	58	
50 mm lead	34	36	34	γ

What type(s) of radiation does the source emit ?

A. β only
B. γ only
C. β and γ only
D. α, β and γ

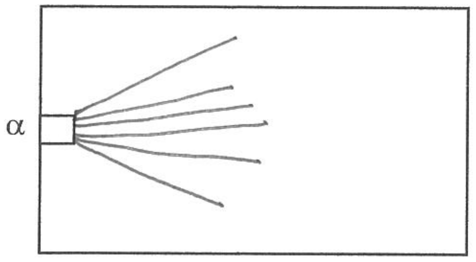
(iii) Cloud Chamber（雲室）



- ✧ **Cloud chamber can detect the tracks of the individual particle.**
- ✧ **All the 3 types of radiations can be detected.**
- ✧ **Each ionizing particle leaves a track in the Cloud chamber.**
- ✧ **The range and ionizing power of the radiation can be observed from the track.**

4. Track of radioactive particles in a Cloud Chamber (雲室中放射粒子的徑跡)

(i) Tracks of alpha particles (α 粒子的徑跡) 考



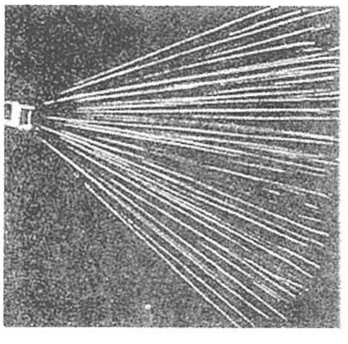
✧ **Characteristics of the tracks produced by α-particles :**

① **straight** – since they have large mass

② **thick** – since they have strong ionizing power

③ **equal length** – since each α particle carries same amount of energy

④ **short** – since α particles have short range in air

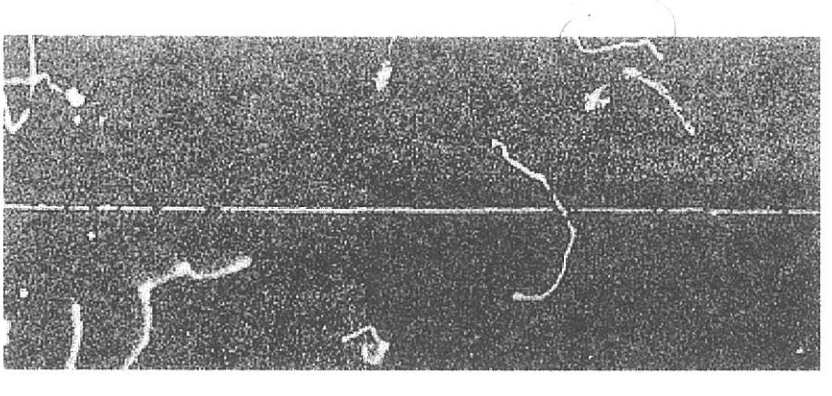


(ii) Tracks of beta-particles (β 粒子的徑跡)

✧ **The tracks are**

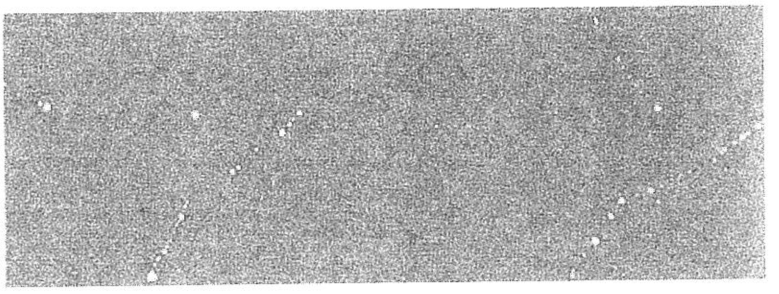
① **thin** – since β has weak ionizing power

② **curved** – since β has small mass



(iii) Tracks of gamma-rays（γ 射線的徑跡）

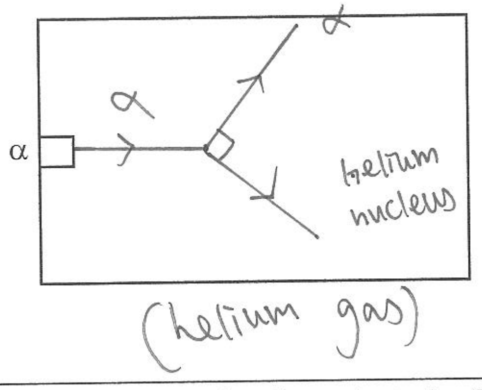
✧ **The tracks are hardly seen since the ionizing power of γ is very weak.**

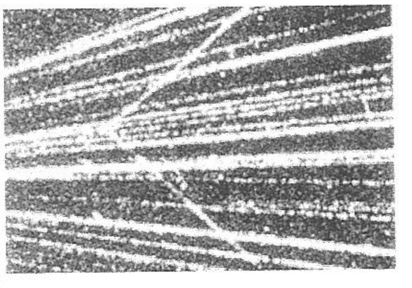


(iv) The right-angled fork track of α particle（α 粒子的直角叉狀徑跡）

✧ **If a cloud chamber containing some helium gas is used to observe the tracks of α particles, then a right-angled fork track may be observed.**

✧ **The fork track in cloud chamber shows that an alpha particle and a helium nucleus have the same mass.**





Example : A cloud chamber is used to observe the tracks of α-particles.
(1993)

(a) Describe the tracks of α-particles in the cloud chamber. (2 marks)

The tracks are (ANY TWO) : [2]

* **straight**
* **thick**
* **short**
* **of about the same length**

(b) An α-particle collides with a helium nucleus to form a fork track. What is the angle of the fork track and what does this angle indicate ? (2 marks)

The angle is 90^o [1]

The masses of an α particle and a helium nucleus are the same. [1]

5. Background radiation（本底輻射）

(i) Sources of background radiation（本底輻射的來源）

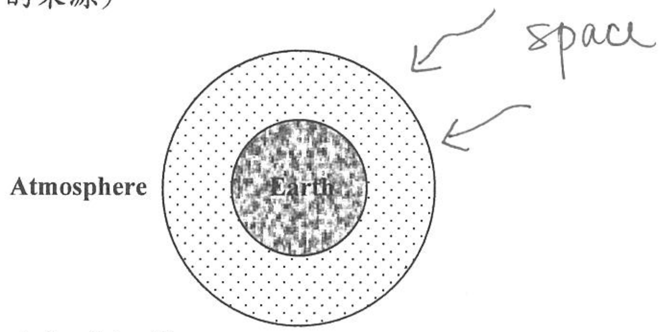
① **Cosmic radiation**（宇宙輻射）**from space**

② **Radiation from rock**

③ **Radiation in air**

④ **Radiation from food**

⑤ **Radiation from human bodies, living things and dead bodies**



Example : Which one of the following does **not** contribute to background radiation ?

A. Dead matter

B. Living matter

C. Mobile phones

D. Rocks

Example : What is the major source of background radiation

(1989) (i) at an altitude of 10000 m above sea-level ;

(ii) inside the Lion Rock Tunnel ;

(iii) in an underground coal mine ? (3 marks)

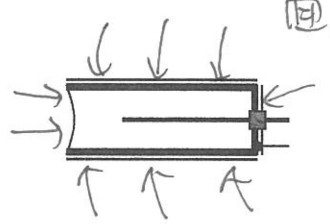
(i) **cosmic radiation from the outer space** [1]

(ii) **radiation from the rock** [1]

(iii) **radiation from the coal (or carbon)** [1]

(ii) Count rate due to background radiation（本底輻射的計數率）

可以透过其他方面入



✧ **A GM counter** (GM tube connected with counter) **can measure the count rate of radiation of a radioactive sample.**

✧ **If no radioactive sample is present, the GM counter can still give a reading. This reading is due to the background radiation.**

✧ **The count rate of the background radiation may vary at different locations and different environments.**

✧ **The count rate of the background radiation is rather constant at a particular location on the surface of the Earth. The slight variation is due to the random nature of radiation.**

✧ **When the GM counter is used to measure the radiation of a radioactive sample, the rate must include the background radiation.**

(iii) Corrected count rate（修正計數率）

✧ **The count rate of a radioactive sample that has deducted the background count rate is called the corrected count rate.**

corrected count rate = measured count rate − background count rate

✧ **The corrected count rate represents the actual number of radioactive particles entering the GM tube.**

Example : A radioactive source is placed in front of a GM tube connected to a counter. Various absorbers are placed between the source and the GM tube and the count-rate recorded. The following results were obtained :

Absorber	Counts per minute
no absorber	700
a sheet of paper	300
2 mm thick aluminium sheet	300
25 mm thick lead block	100

α

no β.

γ ← 200: part of γ

γ + background

Which of the following statements is/are correct ?

✓ (1) The count rate due to alpha radiation is about 400 counts per minute. 700−300

✗ (2) The count rate due to gamma radiation is about 200 counts per minute. 5係吸曬

✗ (3) The background radiation is about 100 counts per minutes.

Example : To investigate the kind(s) of radiation emitted by a radioactive source, a Geiger-Muller counter is placed close in front (1999) of the source and sheets of different absorbers are placed in turn between the source and the counter. Three readings are taken at one-minute intervals for each absorber. The following results are obtained :

Absorber	Recorded count rate / counts per minute		
	1st reading	2nd reading	3rd reading
–	700	710	693
Paper	702	703	701
1 mm Aluminium	313	320	317
5 mm Lead	98	101	100

← no γ

The background count rate recorded by the counter is 100 counts per minute.

(a) Explain why the three readings for each absorber are not identical. (1 mark)

This is due to the random nature of radiation. [1]

(b) Explain how the above results show that the source emits β only and it does not emit α and γ radiation. (4 marks)

α radiation is stopped by a piece of paper. β radiation is partially absorbed by 1 mm aluminium. γ radiation is partially absorbed by 5 mm lead. [1]

As the count rates remain approximately unchanged when a sheet of paper is inserted, the source does not emit α radiation. [1]

As the count rates drop significantly when 1 mm aluminium sheet is inserted, the source emits β radiation. [1]

As the count rates drop to background radiation when 5 mm lead is inserted, the source does not emit γ radiation. [1]

Example : Different absorbers are placed in turn between a radioactive source and a Geiger-Muller tube. Three readings are taken for each absorber. The following data are obtained :

Absorber	Count rate / s^{-1}		
–	200	205	198
Paper	197	202	206
1 mm aluminium	112	108	111
25 mm lead	60	62	58
50 mm lead	58	64	60

no α
β
β
no γ
background

What type(s) of radiation does the source emit ?

A. β only
B. γ only
C. β and γ only
D. α, β and γ

Example : A radioactive source is placed in front of a GM tube connected to a counter. Various absorbers are placed between the [1990] source and the GM tube and the count-rate recorded. The following results were obtained :

Absorber	**Counts per minute**
no absorber	711
a sheet of paper	508
5 mm thick aluminium sheet	493
25 mm thick lead block	218

α
no β
γ

It can be deduced from these results that the radiation(s) emitted by the source is/are

A. α and γ rays only
B. β and γ rays only
C. α rays only
D. β rays only

Example : A GM counter is placed close to and in front of a radioactive source which emits both α and γ radiation. The count rate [2000] recorded is 500 counts per minute while the background count rate is 50 counts per minute. Three different materials are placed **in turn** between the source and the counter. The following results are obtained.

Material	Recorded count rate / counts per minute
(Nil)	500
Cardboard	x
1 mm of aluminium	y
5 mm of lead	z 諗先. ~~0~~ ~~50~~ >50

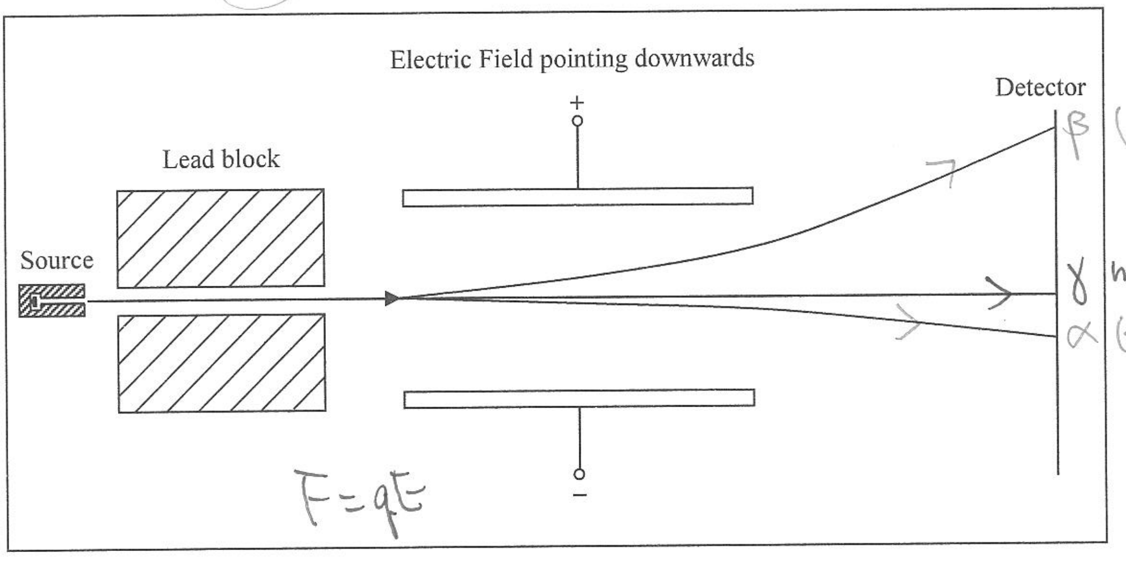
Which of the following is a suitable set of values for x, y and z ?

	x	y	z
A.	350	350	150
B.	350	150	50
C.	350	150	0
D.	150	150	50

6. Deflection of radiation particles（放射粒子的偏轉）

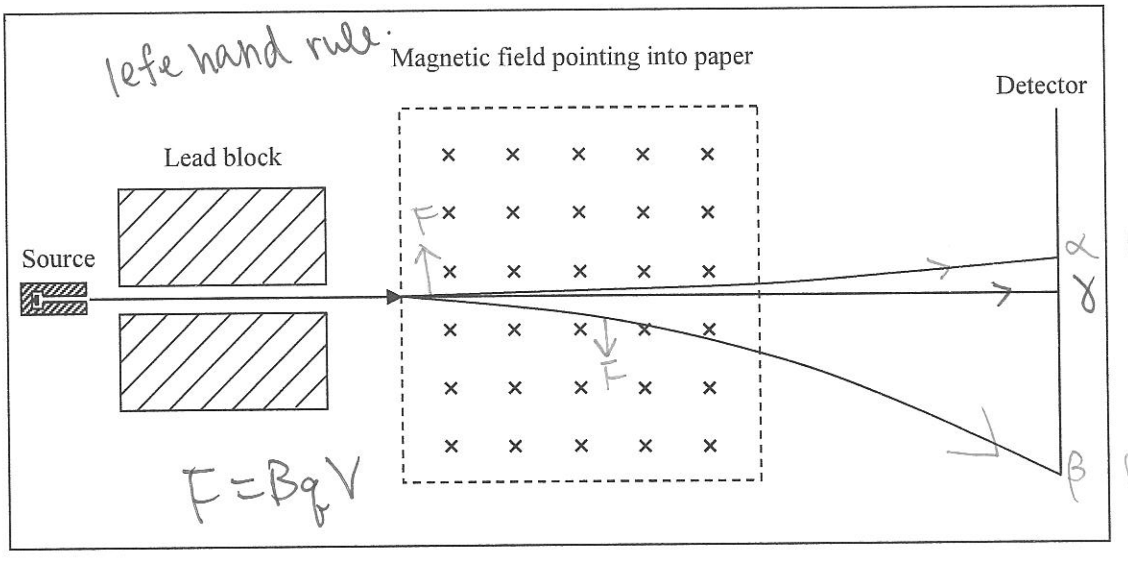
(i) Deflection of radiation in an Electric field（放射粒子在電場的偏轉）

- ✧ The experiment must be done in vacuum（真空）since α has a very short range in air.
- ✧ The lead blocks act as a collimator to give a fine beam of radiation.
- ✧ Both the GM tube and the photographic film can be used as detector.
- ✧ Only α and β radiation are deflected.
- ✧ The path inside the electric field is parabolic.
- ✧ Since β is much lighter than α, the deflection of β is much greater than that of α.



(ii) Deflection of radiation in a Magnetic field（放射粒子在磁場的偏轉）

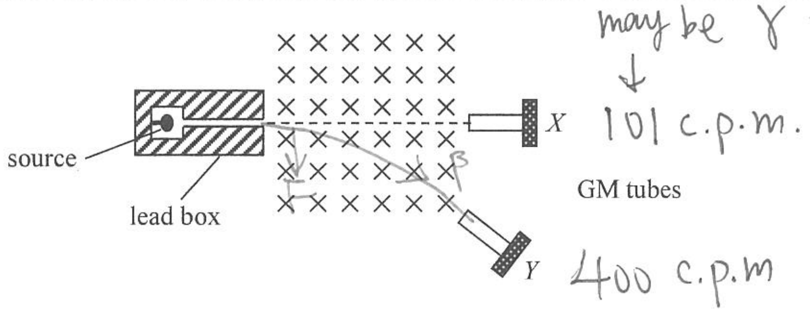
- ✧ The path inside the magnetic field is circular.
- ✧ Since β is much lighter than α, the deflection of β is much greater than that of α.



Example : Which of the following particles **cannot** be deflected by a magnetic field ?
(2002)
A. α-particles +
B. β-particles −
C. neutrons
D. protons +

Example : Which of the following statements about α particles and γ rays is correct ?
(2000)
A. Both of them are transverse waves.
B. Both of them can be deflected by a magnetic field.
C. Both of them have strong ionizing power.
D. Both of them can travel through a vacuum.

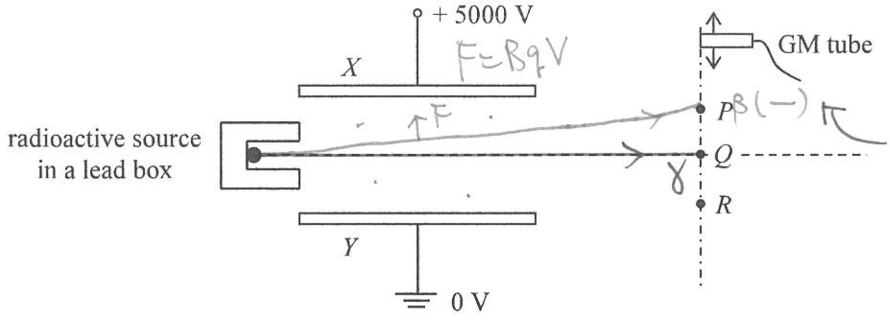
Example :
{PP}



A radioactive source is placed in front of a uniform magnetic field pointing into the paper as shown above. The count rates recorded by the GM tubes at X and Y are 101 counts per minute and 400 counts per minute respectively. Which of the following deductions must be correct ?

A. The source does not emit α radiations.
B. The source emits β radiations.
C. The source emits γ radiations. ?
D. The background count rate is about 100 counts per minute. ?] not sure.

Example :
(2011)



left hand rule
-ve charge
負掉轉

The figure shows a radioactive source placed near two parallel metal plates X and Y that are connected to a power supply. When a GM tube is moved along the dotted line (– · – · –), the count rate shows a significant increase at P and Q respectively. Which of the following statements is correct when a magnetic field pointing out of paper is applied between X and Y ?

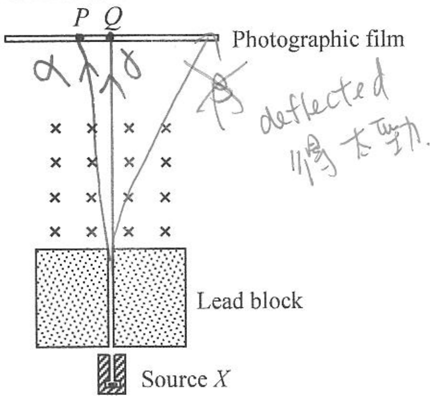
A. The count rate at P decreases and the count rate at Q remains the same.
B. The count rates at P and Q remain the same.
C. The count rate at P decreases and the count rates at Q and R increase.
D. The count rates at P, Q and R are equal.

Example : Which of the following statements about α particles and γ rays is/are correct ?

(2003)
(1) They can both be deflected by a magnetic field.
(2) α particles have a stronger ionizing power than γ rays.
(3) They are emitted with almost the same speed in radioactive decay.

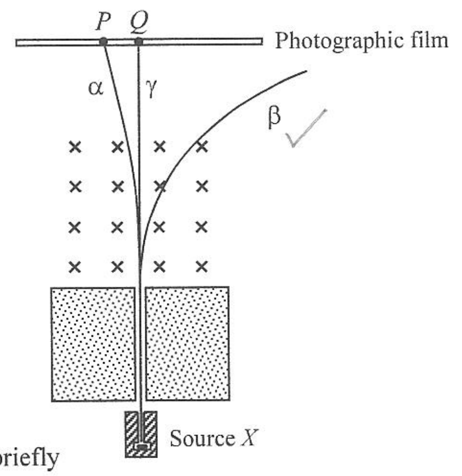
A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

Example :
(1990)



The above figure shows the set-up of an experiment carried out in an evacuated chamber to study the radiation from a radioactive source *X*. *X* emits α, β and γ radiation. A magnetic field (pointing into the paper) is applied. The photographic film is developed and marks in the positions *P* and *Q* are observed.

(a) In the figure below, sketch and label the paths of the α, β and γ radiation emitted from the source *X*. (5 marks)



< 2 rays reaching *P*, *Q* > [1]

< α radiation > [1]

< γ radiation > [1]

< β radiation – towards the right > [1]

< β radiation not reaching the film > [1]

(b) Explain briefly

(i) why the experiment is carried out in an evacuated chamber. (2 marks)

(ii) the use of the lead block in the set-up. (2 marks)

(i) **α-particles have short range in air.** [2]

(ii) **To produce a fine beam of radiation** [2]

(c) If a piece of cardboard is placed between the source and the lead block, what type(s) of radiation would be recorded on the photographic film ? (2 marks) 有β ~~β, γ~~

γ radiation only [2]

(d) Suggest an alternative detector to replace the photographic film in the experiment. (2 marks)

GM tube [2]

7. Activity (放射強度)

(i) Radioactive decay in unstable nucleus (不穩定核的放射衰變)

- ✧ **Radioactive radiation (α, β or γ) is emitted by unstable nucleus.**
- ✧ **After the emission of a radioactive particle, the nucleus is said to undergo decay.**
- ✧ **Only one particle would be emitted in each radioactive decay.**

(ii) Definition of activity (放射強度的定義)

- ✧ **Activity A of a radioactive sample is the number of radioactive particles emitted in unit time.**

  $A = 1000$ Bq.

- ✧ **Since the decay of one nucleus would only emit one radioactive particle, activity is equal to the number of disintegrations (核分裂) in one second, also called the rate of decay (衰變率).**
- ✧ **SI unit of activity** : Bq (Becquerel 貝可勒爾)

  1 Bq = 1 count s^{-1} = 1 decay s^{-1} = 1 disintegration s^{-1} = 1 s^{-1}

- ✧ **Number of particles ΔN emitted in a time interval Δt :**

  $$\boxed{\Delta N = A\,\Delta t}$$ $(\Delta t << T_{\frac{1}{2}})$

  provided the activity remains unchanged during this time interval Δt

- ✧ **Power P given out by the radioactive source :**

  $$\boxed{P = EA}$$ $\left(A = \frac{N}{t}\right)$ $(P \propto A$ for same $E)$

  where E is the energy of one radioactive particle

Example : A radioactive source undergoes β decay. The activity of the source is 2500 Bq.

(a) Find the number of β particles emitted by the source in 2 minutes, assume that the activity remains unchanged in this time interval.

$\Delta N = A\,\Delta t = 2500(2 \times 60) = 3 \times 10^5$

(b) If each β particle carries an energy of 3.3 MeV, calculate the power emitted by the source.

$P = EA = (3.3 \times 10^6 \times 1.6 \times 10^{-19}) \times 2500 = 1.32 \times 10^{-9}$ W

(c) A GM tube placed close to the source measures a corrected count rate of only 250 counts per second. Give ONE reason why the GM tube cannot measure the activity of the source.

Since the particles are emitted in random **directions, not** all **particles can enter the GM tube.**

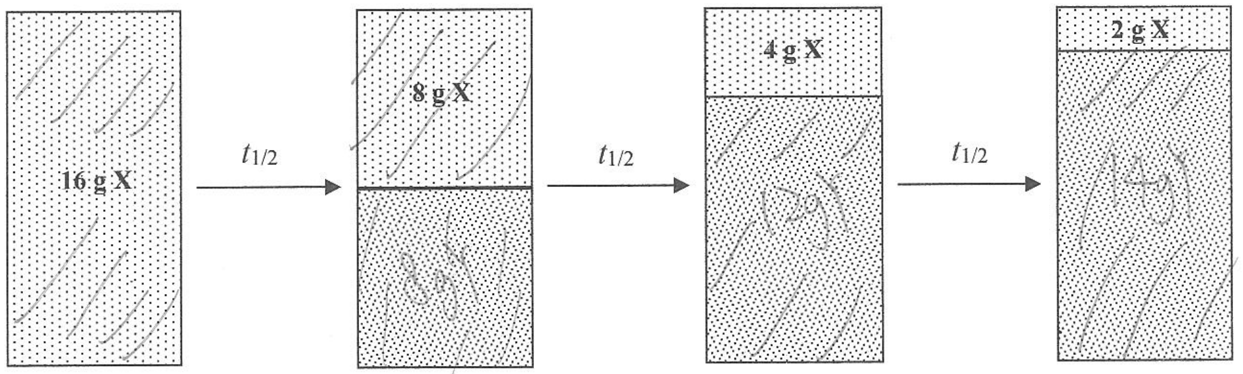
8. Half-life（半衰期）

(i) Definition of half-life（半衰期的定義）

Half-life is the time taken for the activity of a radioactive sample to decrease to half of its original value.

✧ **Since the activity depends on the number of the radioactive nuclei, half-life of a radioactive nuclide is the time taken for half of the radioactive nuclei to decay.**

✧ **Suppose in a sample** (specimen), **nuclide X decays and changes into another nuclide Y with a half-life of $t_{1/2}$. The sequence of the change of mass of the two nuclides X and Y :**



16 g of sample　　16 g of sample　　16 g of sample　　16 g of sample

✧ **Note that the total mass of the sample** (specimen) **remains unchanged.**

✧ **Half-life is a constant depends on the particular nuclide**（核素）**only. It is not affected by human factors or surrounding factors.**

Example : Which of the following descriptions of the half-life of a sample of radioactive isotope is/are correct ?
(1987) The half life is

constant.

(1) the time taken for the mass of the sample to fall to half of its initial value.
(2) the time taken for the activity of the sample to fall to half of its initial value.
(3) half of the time taken for the sample to decay completely. ∞

A. (1) only
B. (2) only
C. (3) only
D. (1) & (2) only

Example : A radioisotope X has a half-life of 2 days while another radioisotope Y has a half-life of 1 day. Initially there are N
(2006) undecayed atoms of X and 8 N undecayed atoms of Y. After how many days will X and Y have the same number of undecayed atoms ?

A. 3 days
B. 4 days
C. 6 days
D. 8 days

$$X : N \xrightarrow{\text{2 days}} \tfrac{1}{2}N \xrightarrow{2} \tfrac{1}{4}N \xrightarrow{2} \tfrac{1}{8}N$$

$$Y : 8N \xrightarrow{1d} 4N \xrightarrow{1} 2N \xrightarrow{1} N \xrightarrow{1} \tfrac{1}{2}N \xrightarrow{1} \tfrac{1}{4}N \xrightarrow{1} \tfrac{1}{8}N$$

(ii) Equations for calculation involving half-life (有關半衰期的計算方程式)

✧ **The activity of a radioactive nuclide after time *t* can be calculated by :**

① finding the number of half-lives n

$$n = \frac{t}{t_{1/2}}$$

② calculating the activity after n half-lives

$$A = A_o \left(\frac{1}{2}\right)^n$$

$A = A_0 \left(\frac{1}{2}\right)^{t/t_{\frac{1}{2}}}$

✧ **The activity *A* of a nuclide is proportional to the number *N* of undecayed nuclei, which in turns proportional to its mass *m* of the radioactive nuclei.**

$\therefore \; N = N_o \left(\frac{1}{2}\right)^n$ $\qquad \therefore \; m = m_o \left(\frac{1}{2}\right)^n$ $\qquad (A \propto N \propto m)$

Example : The initial activity of a radioactive isotope is 2000 integrations per second. After 4 hours, the activity of the isotope drops to 125 disintegrations per second. Find the half-life of the isotope.
(2001)

A. 15 minutes

B. 30 minutes

C. 48 minutes

D. 60 minutes

$2000 \rightarrow 1000 \rightarrow 500 \rightarrow 250 \rightarrow 125$

$4t_{\frac{1}{2}} = 4h$

Example : A certain radioactive isotope X has a half-life of 20 hours. After a time interval of 10 hours, what is the approximate fraction (f) of a sample of the radioactive isotope X remaining ?
{2012}

A. $\frac{1}{4} \leq f \leq \frac{1}{2}$

B. $f = \frac{1}{2}$

C. $\frac{3}{4} > f > \frac{1}{2}$

D. $f > \frac{3}{4}$

$N = N_0 \left(\frac{1}{2}\right)^{t/t_{\frac{1}{2}}}$

$f = \frac{N}{N_0} = \left(\frac{1}{2}\right)^{10/20} = 0.707$

Example : Polonium-210 is a pure α-emitter with a half-life of 140 days and it will decay into lead, which is stable. Initially there is a sample containing 420 mg of pure polonium-210. Estimate the mass of polonium-210 left after 70 days.
{2013}

A. 315 mg

B. 297 mg

C. 210 mg

D. 105 mg

$m = m_0 \left(\frac{1}{2}\right)^{t/t_{\frac{1}{2}}}$

$= 420 \left(\frac{1}{2}\right)^{70/140} = 297$

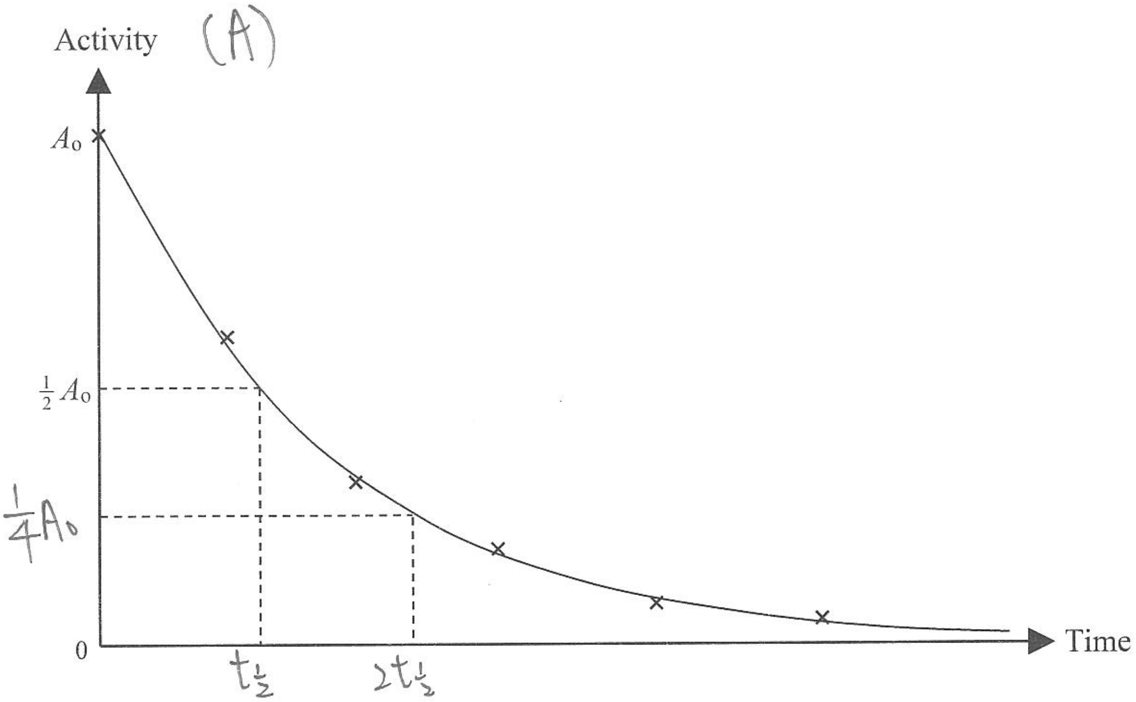
9. Decay curve (衰變曲線)

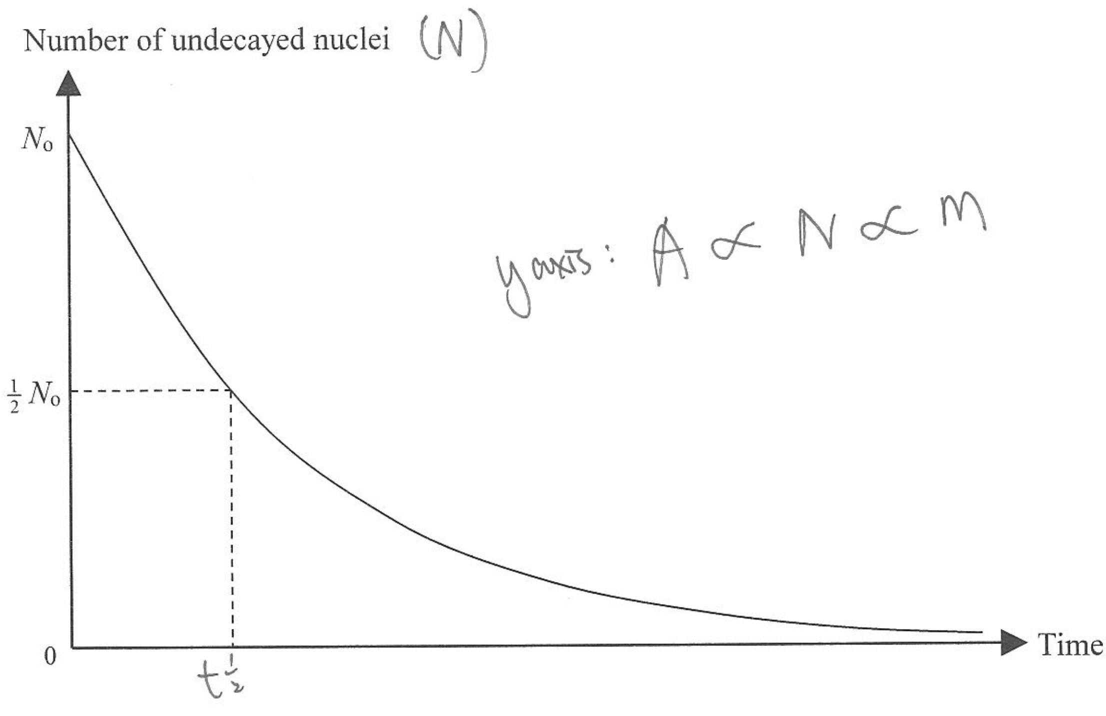
(i) Time variation of the activity (放射強度隨時間的改變)

✧ **A decay curve is obtained when the activity of a radioactive sample is plotted against the time.**

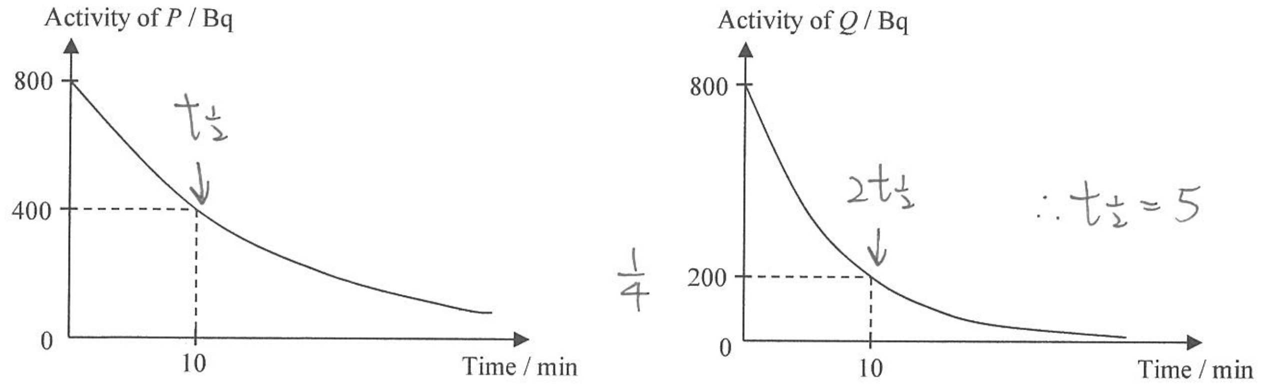
✧ **The plotted points may be scattered at two sides of the curve due to the random nature of radiation.**

✧ **Half-life can be determined from the decay curve.**





Example :
(2003)

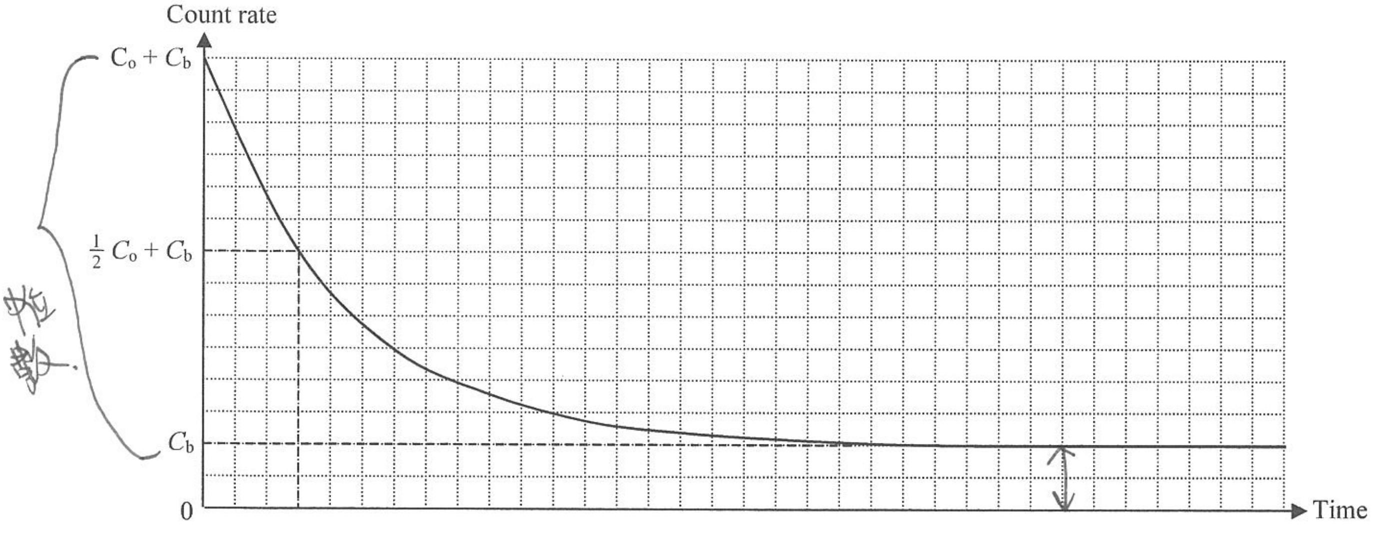


The figures above show the variation of the activities of two radioactive sources P and Q with time. Find the ratio of the half- life of P to that of Q.
10/5

A. 1 : 1   B. 1 : 2   C. 2 : 1   D. 4 : 1

(ii) Curve of count rate against time (計數率與時間的曲線圖)

- ✧ **The total count rate includes the count rate of background radiation.** C_b
- ✧ **The final reading after all the nuclei have been decayed is the background radiation.**



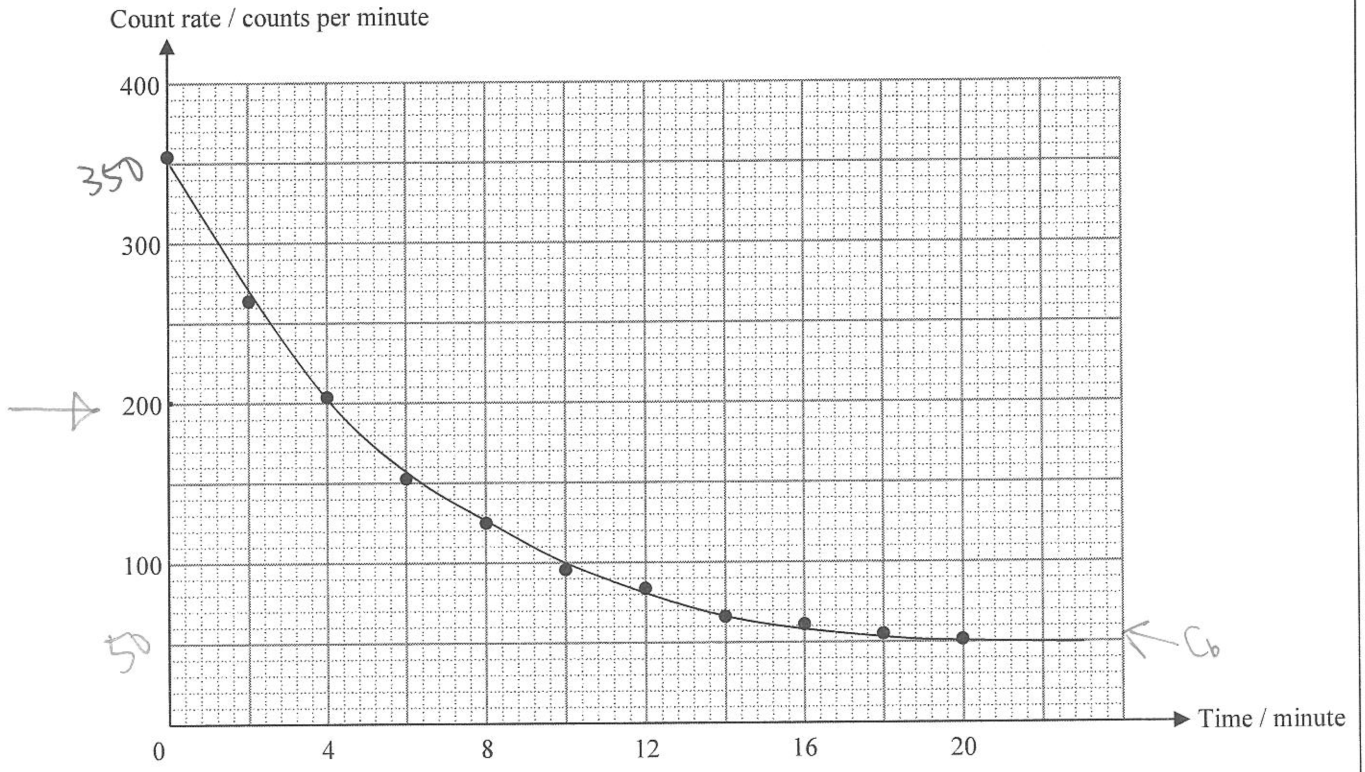
Example : In an experiment to measure the half-life of a radioactive isotope in a place where the background count rate is 20 counts
(1990) per minute, the following results are recorded :

Time / minute	0	2	4	6	8	10	12
Total count rate / counts per minute	116	96	80	69	58	50	44

The half-life is about   Corrected 96 76 60 49
A. 4 min.
B. 6 min.
C. 8 min.
D. 10 min.

$46 \times \frac{1}{2} = 48 \approx 49$

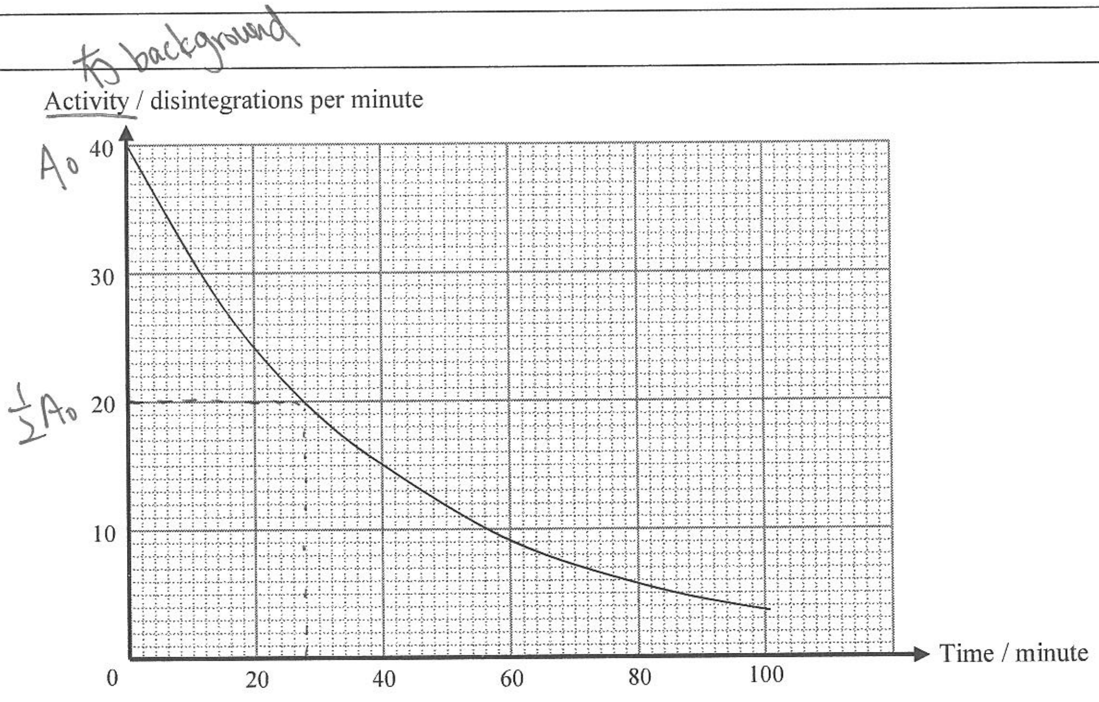
Example : (2007) Susan performs an experiment in which a radioactive source is placed closely in front of a GM counter. The graph below shows the variation of count rate with time.



What is the half-life of the radioactive substance ?

A. 4 minutes B. 5 minutes C. 8 minutes D. 10 minutes

Example : (1991)

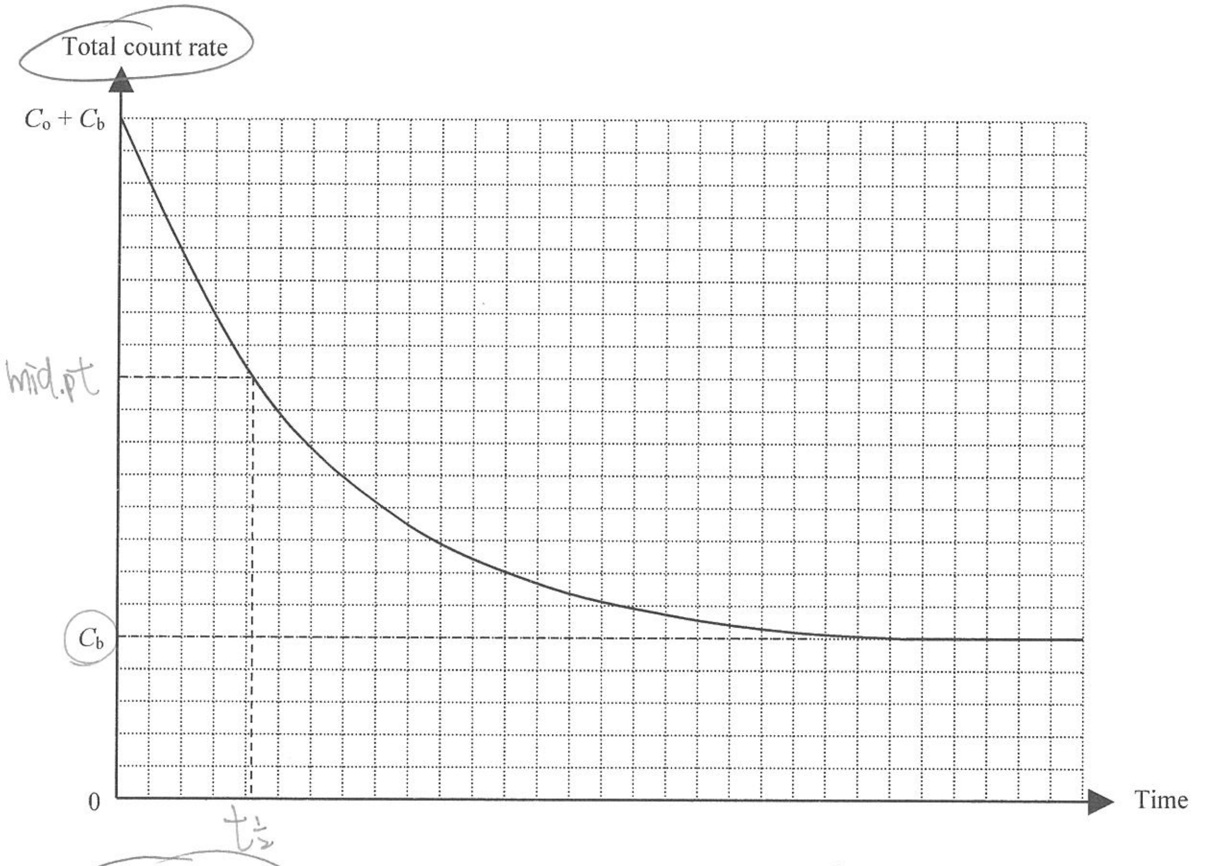


The activity of a radioactive source is recorded on a graph as shown above. What is the half-life of the source ?

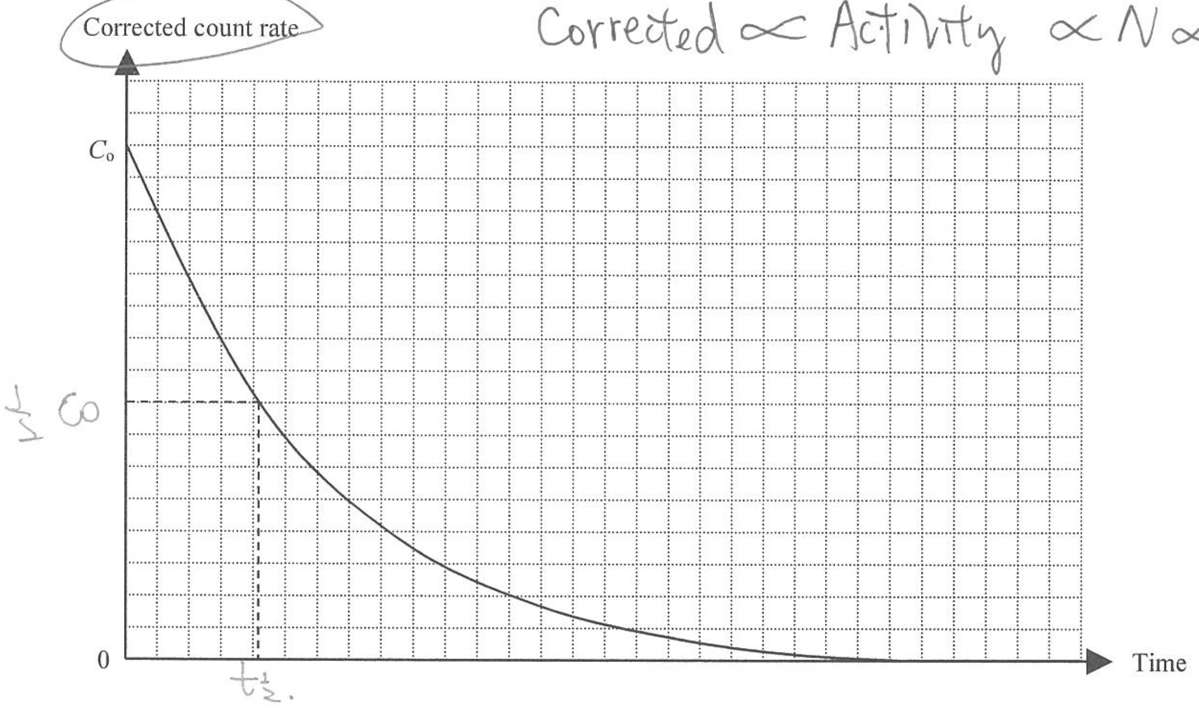
A. 20 min.
B. 24 min.
C. 28 min.
D. 32 min.

(iii) Curve of corrected count rate against time (修正計數率與時間的曲線圖)

- The corrected count rate is the count rate of a radioactive sample that has deducted the background count rate.
- The corrected count rate is then proportional to the activity of the sample.
- The corrected count rate is not equal to the activity since not all the radioactive particles would enter the GM tube to be measured.



Corrected $\propto$ Activity $\propto N \propto m$



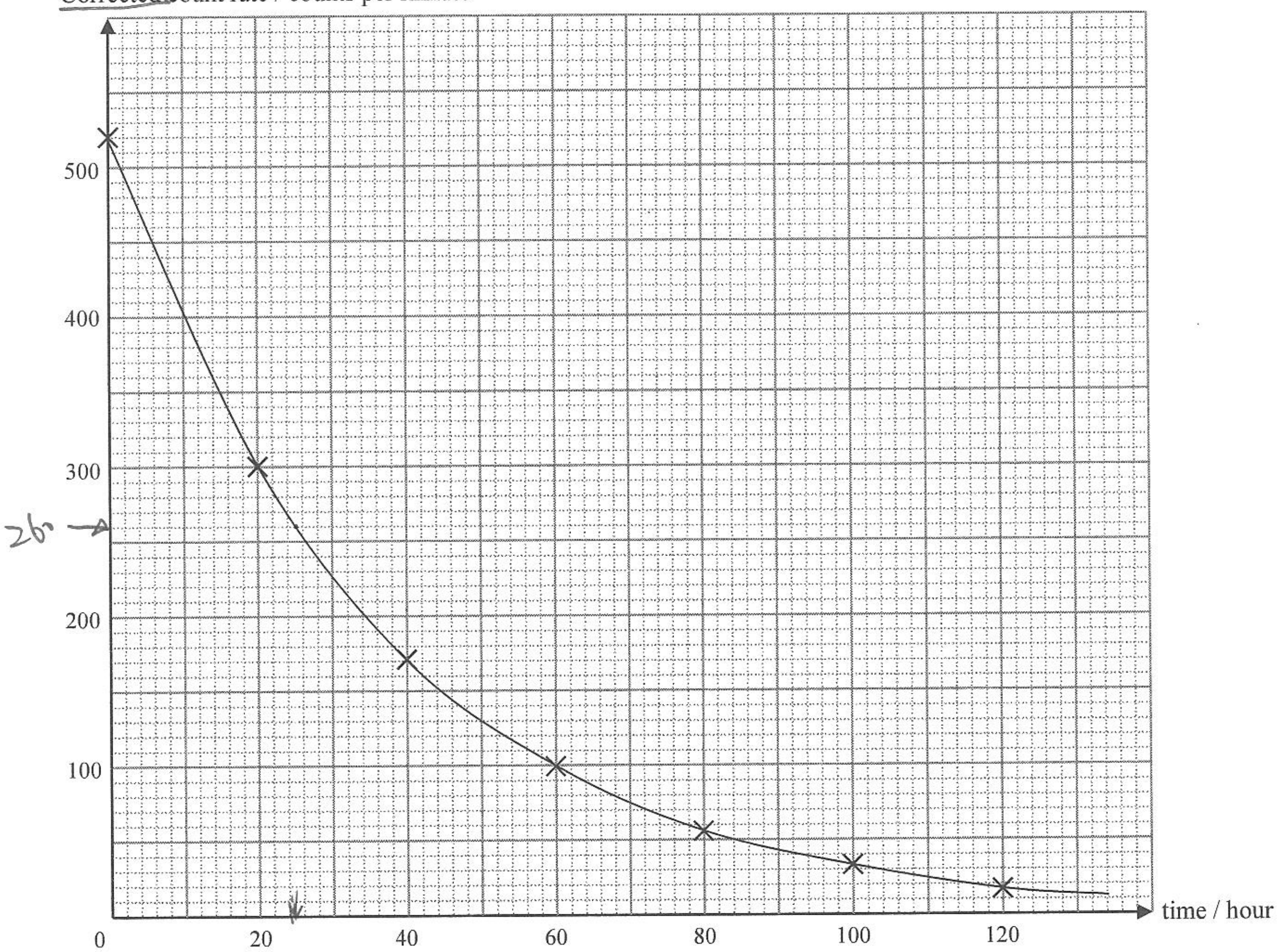
Example : In a school laboratory, the background count rate recorded by a GM counter is 100 counts per minute.
(1995) The counter is placed close in front of a radioactive source *P*. The following results are obtained :

Time *t* / hour	0	20	40	60	80	100	120
Recorded count rate / counts per minute	620	400	270	199	157	133	118

(a) Find the corrected count rate at $t = 0$. (1 mark)

Corrected count rate = 520 counts per minute [1]

(b) Plot the graph of the corrected count rate against time on the graph below. (5 marks)



Time *t* / hour	0	20	40	60	80	100	120
Corrected count rate / counts per minute	520	300	170	99	57	33	18

[1]

< Correct label of the two axes with units > [1]
< An appropriate scale (not less than 1 cm to 50 c.p.m. and 1 cm to 10 hours) > [1]
< Correct points plotted > [1]
< Smooth curve drawn > [1]

(c) Hence find the half-life of the source. (1 mark)

half-life = 25 hours **< from 23 to 27 hours is acceptable >** [1]

Example : The half-life of a radioactive sample is 15 hours. The initial count rate recorded is 1000 counts per minute. After 15 hours, the count rate recorded becomes 528 counts per minute. What is the background count rate ? (Measured in counts per minute.)
(2009)

A. 25

B. 28

C. 50

D. 56

$(1000 - C_b) \times (\frac{1}{2})^{15/15} = 528 - C_b$

$C_b = 56$

Example : The background count rate recorded by a Geiger-Muller counter is 80 counts per minute. When a radioactive source is placed closely in front of the Geiger-Muller tube, the count rate recorded is 560 counts per minute. After 6 hours, the count rate drops to 140 counts per minute. Find the half-life of the source.
(1999)

A. 45 minutes

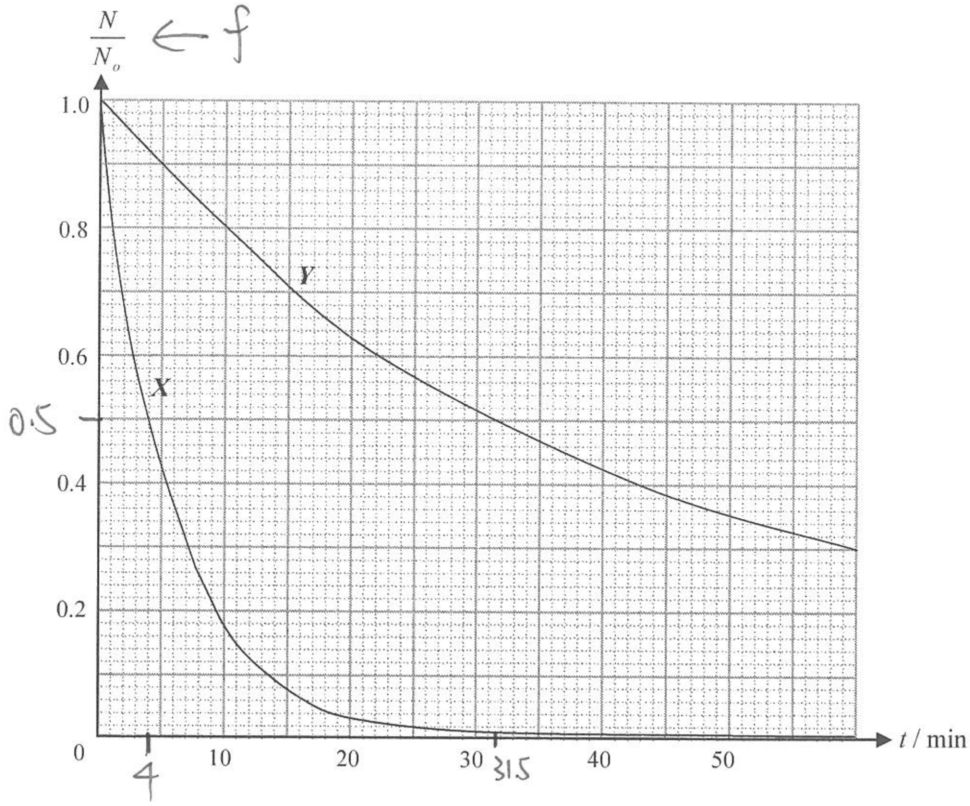
B. 1 hour

C. 1 hour 30 minutes

D. 2 hours

$(560 - 80) \times \frac{1}{2}^{6/t_{\frac{1}{2}}} = 140 - 80$

Example :
(1982)



The above figure show the decay curves of two radioactive elements X and Y both emitting β-particles. N_o is the number of radioactive atoms present at time $t = 0$ and N is the number at the end of t minutes.

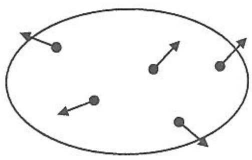
What are the half-lives of X and Y ? (2 marks)

Half-life of X = 4 mins [1]

Half-life of Y = 31.5 mins [1]

10. Characteristics of radioactive decay (放射衰變的特性)

(i) Random nature of decay (放射衰變的隨機特性)

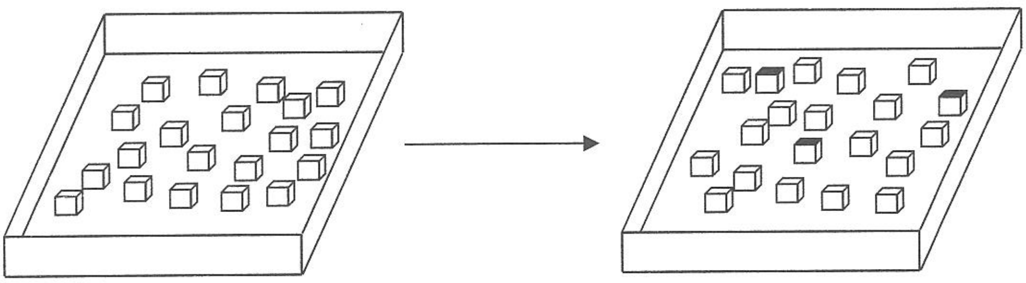


✧ **The emission of radioactive radiation occurs at random.**

① It is impossible to know when one particular nucleus will decay.

② It is impossible to know which nucleus will decay in the next instant.

(ii) Dice decay analogue (擲骰類比)



✧ **A large number of dice is used to represent a sample of radioactive atoms.**

✧ **The dice are shaken and thrown into a tray. Those with a '6' upwards are said to have 'decayed'. These decayed dice are then removed and counted.**

$t_{\frac{1}{2}}$

N: $\boxed{360}$ → 300 → 250 → ... $\boxed{180}$ →

A: 60 50 30

$t_{\frac{1}{2}}$

✧ **The process is random in nature. It is not possible to know which die will be 'decayed' in the next throw.**

✧ **If the number of dice is large, in average about $\frac{1}{6}$ of dice is 'decayed' in each throw.**

$$\therefore \quad -\frac{\Delta N}{\Delta t} = \frac{1}{6} N$$

✧ **Radioactive decay is random in nature. By analogy, a statistical law for rate of decay is**

$$-\frac{\Delta N}{\Delta t} \propto N$$

$A \propto N$

(iii) Decay constant（衰變常數）

- **Since activity is equal to the rate of decay, thus, activity A is proportional to the number of undecayed nuclei N.**

{E3} ✱ $\boxed{A = kN}$ s^{-1}

- **The constant k for a particular radioactive nuclide is called the decay constant.**

- **SI unit of k : s^{-1}**

- **Interpretation of the decay constant k :**

Decay constant k is the probability of decay of the radioactive nuclei per unit time.

(iv) Exponential law of decay（衰變的指數定律）

- **Number of undecayed nuclei N follows the exponential law :**

{E1} ✱ $\boxed{N = N_0 e^{-kt}}$ $(A \propto N \propto m \propto C)$

where N_0 is the original number of undecayed nuclei

and k is the decay constant, with unit s^{-1}

- **Since the activity A or corrected count rate C is proportional to the undecayed nuclei N :**

$$A = A_0 e^{-kt} \qquad\qquad C = C_0 e^{-kt}$$

Example : The activity of a radioisotope is 250 Bq at time $t = 0$ and 54 Bq at $t = 30$ min. Estimate its activity at $t = 10$ min.
[2012]
A. 130 Bq
B. 150 Bq
C. 185 Bq
D. It cannot be found as its half-life is not given.

$A = A_0 e^{-kt}$

$54 = 250 e^{-k(30)}$

$k = 0.0511 \text{ min}^{-1}$

$A = 250 e^{-0.0511 \times 10} = 150$

Example : The activity of a radioactive sample was 70 Bq at time $t = 5$ minutes and 49 Bq at $t = 10$ minutes. Deduce its activity at time $t = 0$.
[2001]
A. 112 Bq
B. 100 Bq
C. 95 Bq
D. 91 Bq

$\left.\begin{array}{l} 70 = A_0 e^{-k(5)} \\ 49 = A_0 e^{-k \times 10} \end{array}\right\} \frac{1}{1}$

$k = 0.0713$

$A = 100$

(v) Relation between the decay constant and the half-life（衰變常數和半衰期的連繫）

✧ **When $t = t_{1/2}$, the activity must drop to half of the initial value, i.e.** $A = \frac{1}{2}A_0$

$\because\ A = A_0 e^{-kt}$ $\therefore\ (\frac{1}{2}A_0) = A_0 e^{-k \cdot t_{1/2}}$ $\therefore\ 2 = e^{k \cdot t_{1/2}}$

$\therefore\ \ln 2 = \ln e^{k \cdot t_{1/2}}$ $\therefore\ \ln 2 = k \cdot t_{1/2}$

{E2} $\boxed{t_{1/2} = \frac{\ln 2}{k}}$ **or** $\boxed{k = \frac{\ln 2}{t_{1/2}}}$

✧ **Since decay constant and half-life are inter-related, exponential decay is described by :**

$\boxed{N = N_0 e^{-kt}}$ $\equiv$ $\boxed{N = N_0 (\frac{1}{2})^{t/t_{1/2}}}$ $A \propto N \propto m$

Example : A nuclide in radioactive sample has a constant chance of 10^{-6} to decay in one second. What is the **approximate** half-life of the sample ?
[2003]

A. 1 day
B. 1 week
C. 1 month
D. 1 year

$t_{\frac{1}{2}} = \frac{\ln 2}{k} = \frac{\ln 2}{10^{-6}} = 6.93 \times 10^{5}$ s ≈ 8 day

(vi) Factors affecting the activity of a radioactive sample（影響放射強度的因素）

① **The decay constant of the radioactive source**（不同的核素）

Activity depends on the decay constant k or half-life of the radioactive source. $\boxed{A = kN}$

② **The number of undecayed nuclei N**（未衰變原子核的數目）

The activity A is proportional to the number of undecayed (active) nuclei N.

Example : On which of the following does the activity of a radioactive source depend ?
{SP}

(1) the nature of the nuclear radiation emitted by the source
(2) the half-life of the source
(3) the number of active nuclei in the source

A. (1) only
B. (2) only
C. (1) & (2) only
D. (2) & (3) only

11. Radiation hazard (輻射的危害)

(i) Harmful Effect of ionizing radiation on people (致電離輻射對人體的有害效應)

- **Radiation can damage cells and tissue in human body.**
- **Radiation can cause cancer (癌症) in human body.**
- **Radiation can cause mutations (異變) and genetic change (基因改變) of body cells and affect the future generations.**
- 累积性
  Effect of radiation is accumulative in the human body for many years.

Example (1989): It is reported that the background radiation in a concrete building is higher than that in a wooden hut. A person thus decides to move to a wooden hut. Do you think that his decision is wise ? Explain briefly. (3 marks)

Both Yes or No are acceptable but the reasons should be consistent. [1]

<u>Reason for Yes</u> : [2]

The cumulative effect of radiation is harmful

<u>Reason for No</u> : (any ONE) [2]

* The background radiation in a concrete building is weak and not hazardous
* The chance of being harmed by other factors such as fire in a wooden hut is increased

(ii) Radiation equivalent dose (輻射有效劑量)

- **We are exposed to background radiation or other man-made sources in our daily life.**
- **Different types of radiation have different degree of hazard (危害) on the human body.**
- **The equivalent dose** (effective dose) **used to measure the amount of radiation received by human body that would cause harmful effect to the body.**
- **The effect of different type of radiation has been considered in the equivalent dose.**
- **The radiation equivalent dose is measured in sievert** (Sv) (希沃特). mSv
- **The following activities may lead to greater radiation equivalent dose :**

  ① cigarette smoking (吸煙)

  ② long distance travelling by air (長途飛行)

  ③ medical examination (醫療檢查)

(iii) Radiation dose in everyday life (日常生活的輻射劑量)

✧ **Different effects of dose level on human bodies :**

- ✱ A large dose of 10 Sv or above is fatal (致命)
- ✱ A dose of 1 to 10 Sv causes acute radiation sickness (急性輻射病)
- ✱ A dose of 0.1 to 1 Sv may cause cancer
- ✱ A dose below 0.1 Sv or 100 mSv (毫希沃特) has no clear health effect

✧ **The average annual dose** (每年平均劑量) **from background radiation is about 2 mSv.**

✧ **Maximum annual dose for a person in public is 5 mSv.**

✧ **Maximum annual dose for a person employed in radiation industry is 20 mSv.**

Example : Some typical radiation doses are tabulated as follows :
[2006]

	Radiation dose
Watching television	0.005 mSv / hr for watching every day in a year
Flying in an aircraft	0.001 mSv / hr
X-ray check	0.020 mSv each time

Arrange the following in ascending order of total radiation dose in one year.

(1) Watching television for 4 hours every day $0.005 \times 4 = 0.02$

(2) Travelling on an aircraft for 10 hours every month $0.001 \times 10 \times 12 = 0.12$

(3) Taking X-ray check every 6 months $0.02 \times 2 = 0.04$

A. (1), (2), (3)
B. (2), (1), (3)
C. (1), (3), (2)
D. (3), (1), (2)

Example : Which of the following actions will maximise a person's exposure to radiation ?
(2008)

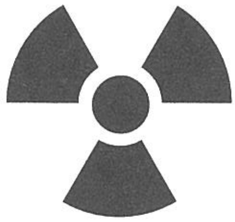
A. Using a GM tube and counter to measure the background radiation in laboratory.

B. Eating food that has been sterilised by exposure to gamma radiation.

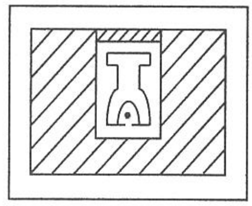
C. Listening to radio.

D. Going for a flight to a distant place in a high-flying aeroplane.

(iv) Warning sign of radiation（放射性物質的警告標誌）



(v) Safety precautions on use of radioactive source（使用放射性物質的安全措施）



① **Use long forceps to handle a radioactive source.**

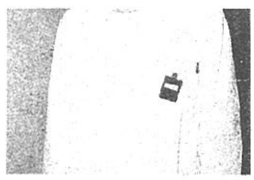
② **Keep the exposure time to radioactive source as short as possible.**

③ **Wear disposable gloves and protective clothing in handling.**

④ **Never point a source towards human bodies.**

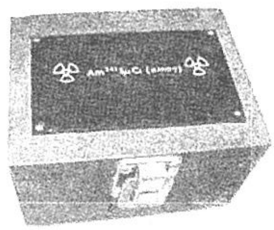
⑤ **No eating, drinking and smoking during the handling.**

⑥ **Store the radioactive source in lead containers.**



⑦ **Workman should monitor the radiation dose by wearing film-badge. If the dose is too high, they should leave the job for a period of time.**

Example : Some dangerous substances are stored in a metal container inside a wooden box as shown in the figure. What metal should be used for the container and what type of substance is stored ?
(2007)



	Metal used	Type of substance stored
A.	Iron	Radioactive
B.	Iron	Flammable
C.	Lead	Radioactive
D.	Lead	Flammable

Example : Which one of the following is **not** a safety precautions for handling radioactive sources ?

(2000) A. Users should not eat or drink when handling radioactive sources.

B. Users should wash their hands after handling radioactive sources.

C. Radioactive sources should not be held close to the eye for visual examination.

D. Radioactive sources should be stored in wooden boxes after use.

Example : Workers of nuclear plants are required to wear film badges (see Figure 1) to monitor their exposure to radiation. Inside the film badge, an opaque plastic bag is wrapped around a sheet of photographic film. Aluminium and lead sheets are also placed inside the badge (see Figure 2) so that the types of incoming radiation can be distinguished.
(2006)

Figure 1

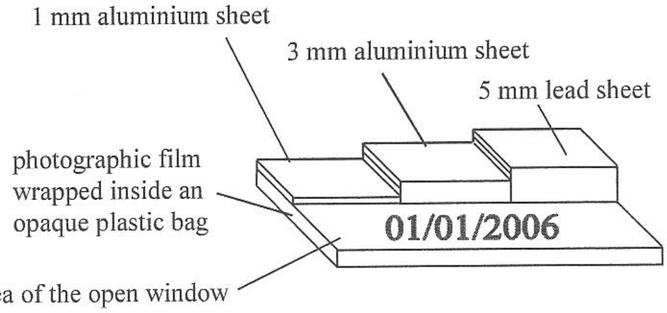


Figure 2

(a) What type(s) of nuclear radiation cannot be detected by the badge ? (1 mark)

α radiation 俾隔左 [1]

(b) Why is an opaque plastic bag used to wrap the photographic film ? (1 mark)

To prevent light rays from entering the bag and blackening the film. [1]

(c) The films of three workers John, Mary and Ken were developed. The Table below shows the degrees of blackening on different regions of the films inside the badges which they wore.

Regions on the film	Degree of blackening (0 – 5) (0 = not blackened; 5 = most blackened)		
	John	Mary	Ken
Beneath the open window	5 no β	5 β	5 β
Beneath the 1 mm aluminium sheet	5	3	4
Beneath the 3 mm aluminium sheet	5 γ	1 <	2
Beneath the 5 mm lead sheet	4	0	0

(i) Based on the results in the above Table, explain which type(s) of radiation John and Mary are definitely being exposed to respectively. (4 marks)

John is exposed to γ radiation [1]

since γ can pass through the 5 mm lead sheet and blacken the film. [1]

Mary is exposed to β radiation since the film under the aluminium sheets is blackened but the film under the 5 mm lead sheet is not blackened. [1]

(ii) Give one reason why different degrees of blackening were recorded on the films of Mary and Ken. (1 mark)

The radiation dose received by Ken is higher than that of Mary. [1]

(d) Suggest one hazard of exposure to ionizing radiations. (1 mark)

Any ONE of the following : [1]

* **It can destroy living cells.**
* **It can cause cancer.**
* **It can cause the genetic change.**

Use the following data wherever necessary :

Charge of electron $e = 1.6 \times 10^{-19}$ C

The following list of formulae may be found useful :

Law of radioactive decay $N = N_0 e^{-kt}$

Half-life and decay constant $t_{\frac{1}{2}} = \dfrac{\ln 2}{k}$

Activity and the number of undecayed nuclei $A = kN$

Part A :

The following questions marked with { } are the past DSE examination questions.

The questions marked with {SP} are the Sample Paper questions.

The questions marked with {PP} are the Practice Paper questions.

The number inside the brackets represents the year of the DSE examination.

M1. On which of the following does the activity of a radioactive source depend ?
{SP}
(1) the nature of the nuclear radiation emitted by the source
(2) the half-life of the source
(3) the number of active nuclei in the source

A. (1) only
B. (2) only
C. (1) & (2) only
D. (2) & (3) only

M2. Different absorbers are placed in turn between a radioactive source and a Geiger-Muller tube. Three readings are taken for {SP} each absorber. The following data are obtained :

Absorber	Count rate / s^{-1}		
–	200	205	198
Paper	197	202	206
5 mm aluminium	112	108	111
25 mm lead	60	62	58
50 mm lead	34	36	34

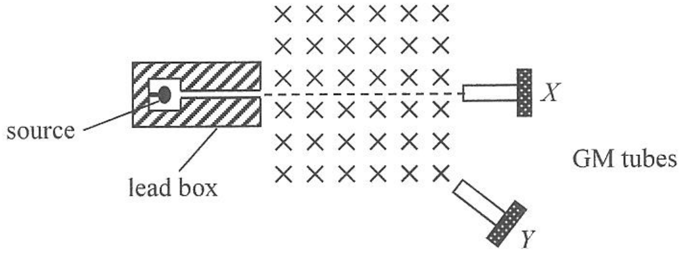
What type(s) of radiation does the source emit ?

A. β only
B. γ only
C. β and γ only
D. α, β and γ

M3. Which of the following statements about α and β particles is/are correct ?
{PP}
(1) The mass of an α particle is greater than that of a β particle.
(2) α particles have a stronger penetrating power than β particles.
(3) An α source can discharge a positively charged metal sphere nearby.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M4.
{PP}



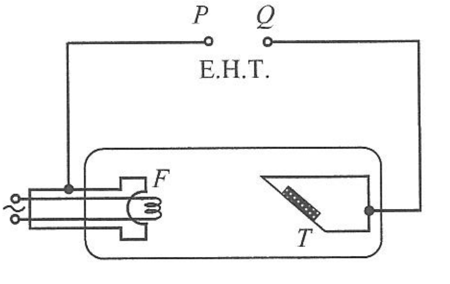
A radioactive source is placed in front of a uniform magnetic field pointing into the paper as shown above. The count rates recorded by the GM tubes at X and Y are 101 counts per minute and 400 counts per minute respectively. Which of the following deductions must be correct ?

A. The source does not emit α radiations.
B. The source emits β radiations.
C. The source emits γ radiations.
D. The background count rate is about 100 counts per minute.

M5. A certain radioactive isotope X has a half-life of 20 hours. After a time interval of 10 hours, what is the approximate
{12} fraction (f) of a sample of the radioactive isotope X remaining ?

A. $\frac{1}{4} \leq f \leq \frac{1}{2}$
B. $f = \frac{1}{2}$
C. $\frac{3}{4} > f > \frac{1}{2}$
D. $f > \frac{3}{4}$

M6. The figure shows a schematic diagram of an X-ray tube in which the
{12} filament F and the metal target T are connected to terminals P and Q of an E.H.T. Which statement is correct ?



A. P is the positive terminal and X-rays are emitted from T.
B. P is the positive terminal and X-rays are emitted from F.
C. Q is the positive terminal and X-rays are emitted from T.
D. Q is the positive terminal and X-rays are emitted from F.

M7. Polonium-210 is a pure α-emitter with a half-life of 140 days and it will decay into lead, which is stable. Initially there is a
{13} sample containing 420 mg of pure polonium-210. Estimate the mass of polonium-210 left after 70 days.

A. 315 mg
B. 297 mg
C. 210 mg
D. 105 mg

M8. A GM counter is placed close to and in front of a radioactive source which emits both α and γ radiations. The count rate {14} recorded is 450 counts per minute while the background count rate is 50 counts per minute. Three different materials are placed in turn between the source and the counter. The following results are obtained.

Material	Recorded count rate / counts per minute
(Nil)	450
cardboard	x
1 mm of aluminium	y
2 mm of lead	z

Which of the following is the most suitable set of values for x, y and z ?

	x	y	z
A.	300	300	100
B.	300	100	50
C.	100	100	0
D.	100	50	50

M9. Some factories make use of radioactive source for manufacturing. Workers are required to wear clothes with film badges to {15} measure the dosage of radiation received over a period of time. Which type of radiation below CANNOT be monitored by the film badges ?
A. α-radiation
B. β-radiation
C. γ-radiation
D. X-rays

Part B :

The following questions marked with ( ) are the past HKCE questions.

The number inside the brackets represents the year of the examination.

M10. In a β decay, element X, having a half-life of 3 days, decays into a stable element Y. If the initial mass of X is 4 g, what will (80) be the masses of X and Y after 6 days ?

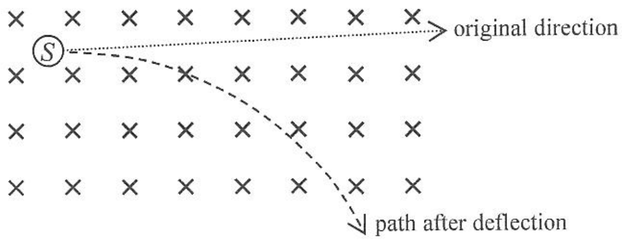
	Mass of X	Mass of Y
A.	0 g	4 g
B.	1 g	3 g
C.	2 g	2 g
D.	3 g	1 g

M11. If the three kinds of radiations α, β and γ are arranged in ascending order of their ionization power, their order is
(81) A. α, β, γ
B. α, γ, β
C. β, α, γ
D. γ, β, α

M12. A radioactive substance has a half-life of 10 minutes. Which of the following statements is/are correct ?
(82) (1) All the atoms of the radioactive substance will split into 4 equal parts in 5 minutes.
(2) All the atoms of the radioactive substance will decay completely in 20 minutes.
(3) All the atoms of the radioactive substance will decay within 10 minutes.
A. (1) only
B. (2) only
C. (3) only
D. None of them

M13. The half-life of a radioactive substance is 8 hours. Its initial mass is 3 g. Find the amount of the radioactive substance
(83) remaining unchanged after 24 hours.
A. 0.375 g
B. 0.75 g
C. 1 g
D. 2 g

M14. S is a radioactive source which emits radiation as it decays.
(84) If all the radiation emitted is bent by a magnetic field in the direction shown, then the radiation consists of



A. α and γ only
B. β and γ only
C. α only
D. β only

M15. The corrected count rate of a sample of radioactive material was measured on the first day of each month. The readings on
(85) July 1 and September 1 are 0.8 and 0.2 counts per second respectively. What is the half-life of the radioactive material ?
A. 7 days
B. 16 days
C. 31 days
D. 46 days

M16. The speeds of X-rays, γ rays and β rays in air are denoted by v_X, v_γ and v_β respectively. Which of the following is true ?
(86) A. $v_X > v_\gamma > v_\beta$
B. $v_X < v_\gamma < v_\beta$
C. $v_X = v_\gamma = v_\beta$
D. $v_X = v_\gamma > v_\beta$

M17. Which of the following about α radiation is/are correct ?
(87) (1) The mass of an α particle is about four times that of a hydrogen atom.
(2) It has a stronger ionizing power than β radiation.
(3) It has a greater penetration power than γ radiation.
A. (1) only
B. (2) only
C. (1) & (2) only
D. (2) & (3) only

M18. Which of the following descriptions of the half-life of a sample of radioactive isotope is/are correct ? The half life is
(87) (1) the time taken for the mass of the sample to fall to half of its initial value.
(2) the time taken for the activity of the sample to fall to half of its initial value.
(3) half of the time taken for the sample to decay completely.
A. (1) only
B. (2) only
C. (3) only
D. (1) & (2) only

M19. The activity of a radioactive source falls to $\frac{1}{8}$ of its original value in 24 minutes. The half-life of the source is
(88) A. 3 min.
B. 6 min.
C. 8 min.
D. 72 min.

M20. A radioactive source has a half-life of 22 years. After 66 years, what fraction of the source remains undecayed ?

(89) A. $\frac{1}{3}$

B. $\frac{1}{6}$

C. $\frac{1}{8}$

D. $\frac{1}{9}$

M21. In an experiment to measure the half-life of a radioactive isotope in a place where the background count rate is 20 counts per
(90) minute, the following results are recorded :

Time / minute	0	2	4	6	8	10	12
Total count rate / counts per minute	116	96	80	69	58	50	44

The half-life is about

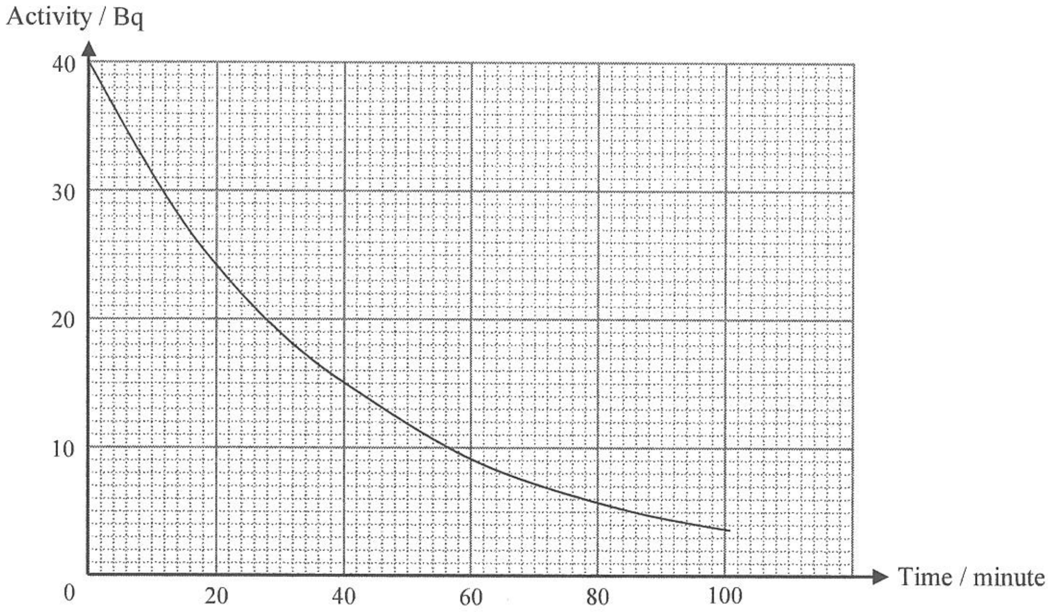
A. 4 min.

B. 6 min.

C. 8 min.

D. 10 min.

M22.
(91)



The activity of a radioactive source is recorded on a graph as shown above. What is the half-life of the source ?

A. 20 min.

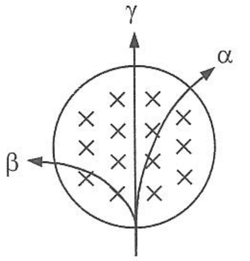
B. 24 min.

C. 28 min.

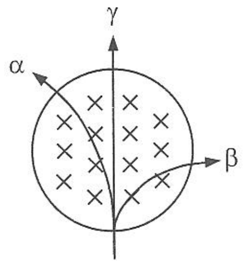
D. 32 min.

M23. Which of the following diagrams correctly shows the deflections of α, β and γ rays in a uniform magnetic field pointing into
(92) the paper ?

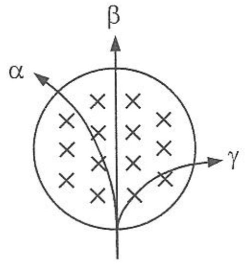
A.



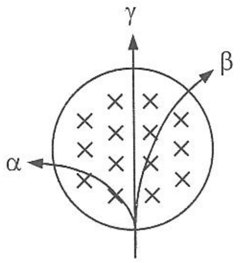
B.



C.

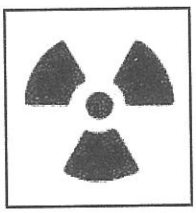


D.

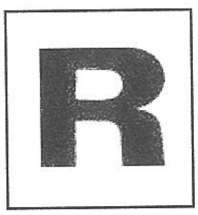


M24. Which of the following signs is used to indicate radioactive material ?
(93) A.

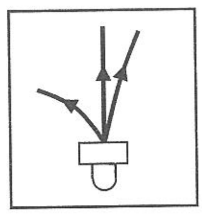
B.



C.



D.



M25. Arrange α, β and γ radiation in ascending order of their ionizing powers :

(94) A. α , β , γ

B. β , γ , α

C. γ , α , β

D. γ , β , α

M26. The activity of a radioactive source drops from 640 Bq to 40 Bq in 2 hours. Find the half-life of the source.

(94) A. 7.5 min.

B. 15 min.

C. 24 min.

D. 30 min.

M27. Which of the following cannot travel through a vacuum ?

(95) A. β particles

B. Infra-red

C. Microwaves

D. Ultrasonics

M28. Which of the following statements about X-rays is/are correct ?
(95) (1) X-rays consist of fast moving electrons.
(2) X-rays can blacken photographic films.
(3) X-rays can be used to detect weapons hidden in luggage.
A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

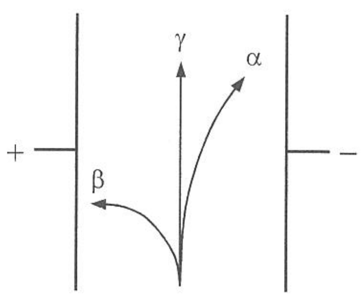
M29. Which of the following can be deflected by both an electric field and a magnetic field ?
(96) (1) α particles
(2) β particles
(3) γ rays
A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M30. The activity of a radioactive isotope falls to $\frac{1}{16}$ of its initial value in one hour. Find the half-life of the isotope.
(96) A. 3.75 minutes
B. 7.5 minutes
C. 10 minutes
D. 15 minutes

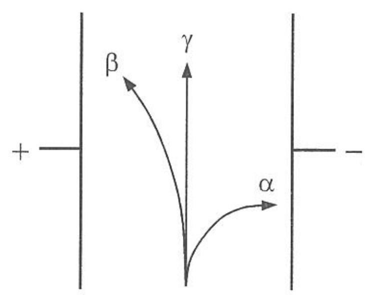
M31. Which of the following statements about β particles is **incorrect** ?
(97) A. β particles can be stopped by a piece of paper.
B. β particles can be deflected by a magnetic field.
C. β particles can blacken photographic films.
D. β particles can travel through a vacuum.

M32. Which of the following diagrams correctly shows the directions in which α, β and γ radiations are deflected in a uniform
(98) electric field produced by two charged metal plates ?

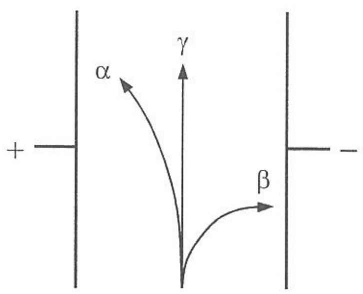
A.



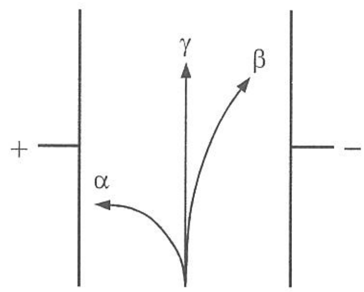
B.



C.



D.



M33. Which of the following statements about α particles is **incorrect** ?
(99) A. α particles can be stopped by a piece of paper.
B. α particles can blacken photographic films.
C. α particles have a range of several centimetres in air.
D. α particles cannot travel through a vacuum.

M34. An insulated metal sphere carries positive charges. Which of the following will discharge the sphere ?
(99) (1) bringing an alpha source near the sphere
(2) touching the sphere momentarily with a finger
(3) bringing a negatively charged metal rod near the sphere (but without touching it)
A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M35. The background count rate recorded by a Geiger-Muller counter is 80 counts per minute. When a radioactive source is
(99) placed closely in front of the Geiger-Muller tube, the count rate recorded is 560 counts per minute. After 6 hours, the count rate drops to 140 counts per minute. Find the half-life of the source.
A. 45 minutes
B. 1 hour
C. 1 hour 30 minutes
D. 2 hours

M36. Which of the following statements about α particles and γ rays is correct ?
(00) A. Both of them are transverse waves.
B. Both of them can be deflected by a magnetic field.
C. Both of them have strong ionizing power.
D. Both of them can travel through a vacuum.

M37. Which one of the following is **not** a safety precautions for handling radioactive sources ?
(00) A. Users should not eat or drink when handling radioactive sources.
B. Users should wear gloves for handling radioactive sources.
C. Radioactive sources should not be held close to the eye for visual examination.
D. Radioactive sources should be stored in wooden boxes after use.

M38. The initial activity of a radioactive isotope is 2000 Bq. After 4 hours, the activity of the isotope drops to 125 Bq.
(01) Find the half-life of the isotope.
A. 15 minutes
B. 30 minutes
C. 48 minutes
D. 60 minutes

M39. Which of the following particles **cannot** be deflected by a magnetic field ?
(02) A. α-particles
B. β-particles
C. neutrons
D. protons

M40. Which of the following statements about α particles and γ rays is/are correct ?

(03)

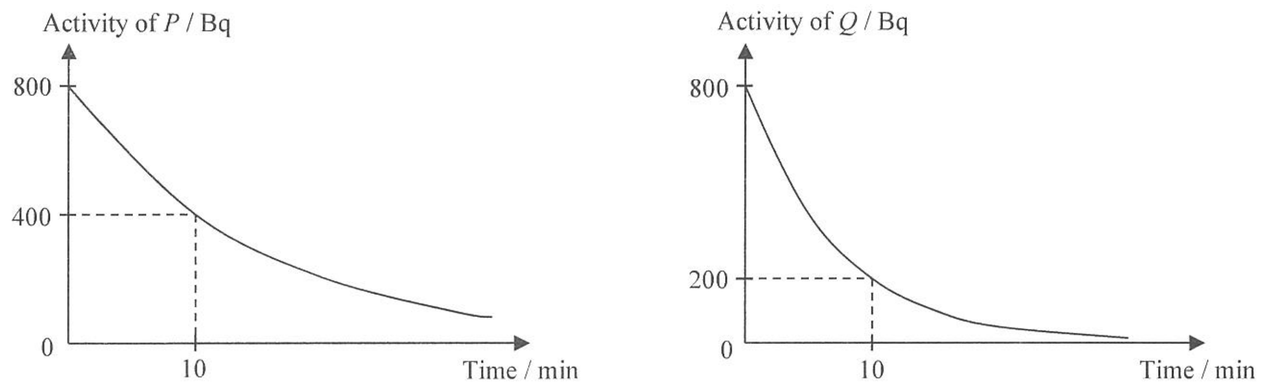
(1) They can both be deflected by a magnetic field.

(2) α particles have a stronger ionizing power than γ rays.

(3) They are emitted with almost the same speed in radioactive decay.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M41.
(03)



The figures above show the variation of the activities of two radioactive sources P and Q with time. Find the ratio of the half-life of P to that of Q.

A. 1 : 1

B. 1 : 2

C. 2 : 1

D. 4 : 1

M42. Different absorbers are placed in turn between a radioactive source and a Geiger-Muller tube. Three readings are taken for
(04) each absorber. The following data are obtained :

Absorber	**Count rate / s^{-1}**		
–	200	205	198
Paper	197	202	206
5 mm aluminium	112	108	111
25 mm lead	60	62	58
50 mm lead	34	36	34

What type(s) of radiation does the source emit ?

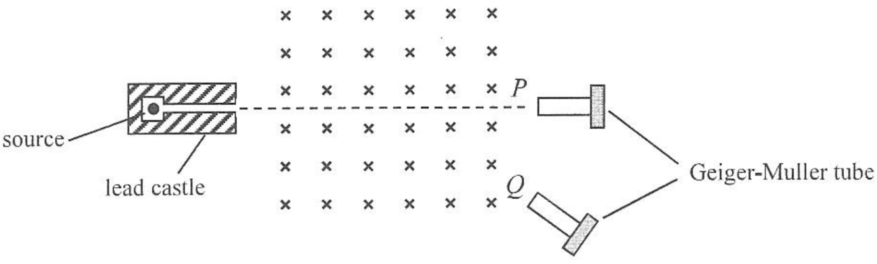
A. β only

B. γ only

C. β and γ only

D. α, β and γ

M43.
(05)



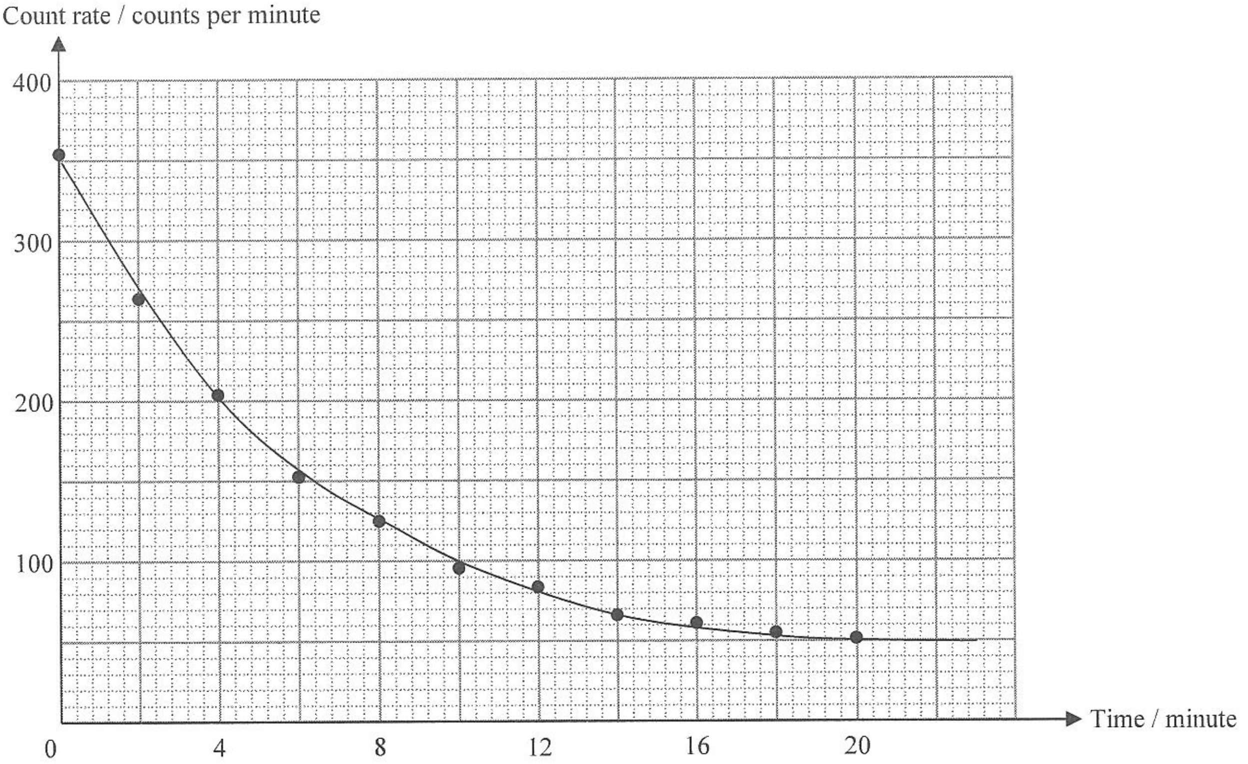
A radioactive source is placed in front of a uniform magnetic field pointing into the paper as shown above. If a high count rate is recorded at positions P and Q, what kinds of radiation have been detected ?

	P	***Q***
A.	γ	α
B.	γ	β
C.	β	α
D.	β	γ

M44. A radioisotope X has a half-life of 2 days while another radioisotope Y has a half-life of 1 day. Initially there are N undecayed
(06) atoms of X and 8 N undecayed atoms of Y. After how many days will X and Y have the same number of undecayed atoms ?

A. 3 days
B. 4 days
C. 6 days
D. 8 days

M45. Susan performs an experiment in which a radioactive source is placed closely in front of a GM counter. The graph below
(07) shows the variation of count rate with time.



What is the half-life of the radioactive substance ?

A. 4 minutes
B. 5 minutes
C. 8 minutes
D. 10 minutes

M46. Some dangerous substances are stored in a metal container inside a wooden box as
(07) shown in the figure. What metal should be used for the container and what type of substance is stored ?

	Metal used	**Type of substance stored**
A.	Iron	Radioactive
B.	Iron	Flammable
C.	Lead	Radioactive
D.	Lead	Flammable

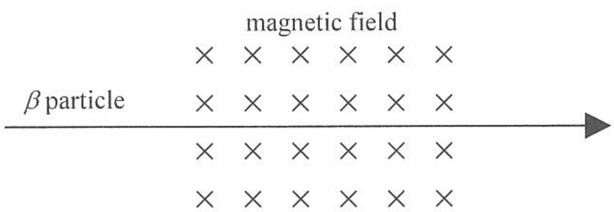
M47. Which of the following descriptions about the half-life of a radioactive substance in a sample is correct ?
(08) A. It is equal to half of the time for all the radioactive nuclei of the substance to decay.
B. It is equal to half of the time for a radioactive nucleus of the substance to decay.
C. It is equal to the time for the sample to reduce its mass by half.
D. It is equal to the time for half of the radioactive nuclei of the substance to decay.

M48. Which of the following actions will maximise a person's exposure to radiation ?
(08) A. Using a GM tube and counter to measure the background radiation in laboratory.
B. Eating food that has been sterilised by exposure to gamma radiation.
C. Listening to radio.
D. Going for a flight to a distant place in a high-flying aeroplane.

M49. Which of the following statements about β particles is correct ?
(08) A. β particles carry positive charge.
B. β particles can be deflected by a magnetic field.
C. β particles cannot be deflected by an electric field.
D. β particles can be stopped by a sheet of paper.

M50. The half-life of a radioactive sample is 15 hours. The initial count rate recorded is 1000 counts per minute. After 15 hours,
(09) the count rate recorded becomes 528 counts per minute. What is the background count rate ? (Measured in counts per minute.)
A. 25
B. 28
C. 50
D. 56

M51.
(10)



In the above figure, a β particle enters a region with a magnetic field pointing into paper and an electric field of unknown direction. The β particle has no deflection. What is the direction of the electric field ?

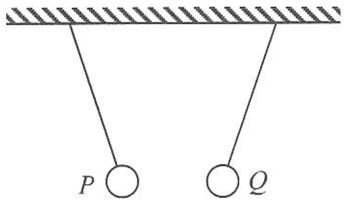
A. ←

B. →

C. ↑

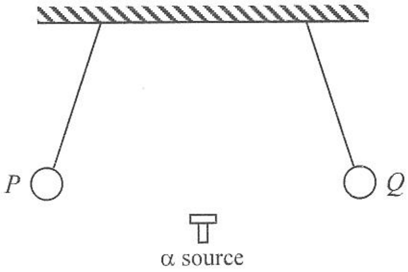
D. ↓

M52.
(10)

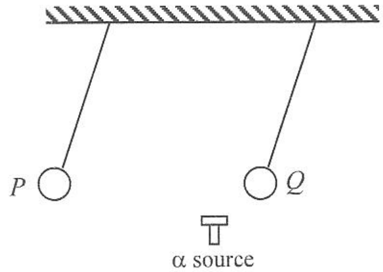


In the figure above, two charged metal balls P and Q are hung by insulating threads. P is positively charged while Q is negatively charged. An α source is put near the balls without touching them. Which of the following figures shows the situation after a period of time ?

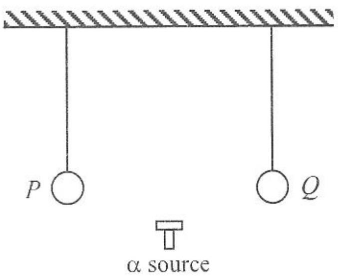
A.



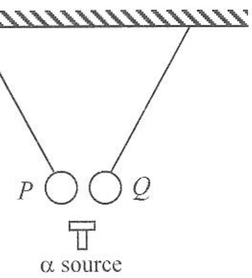
B.



C.



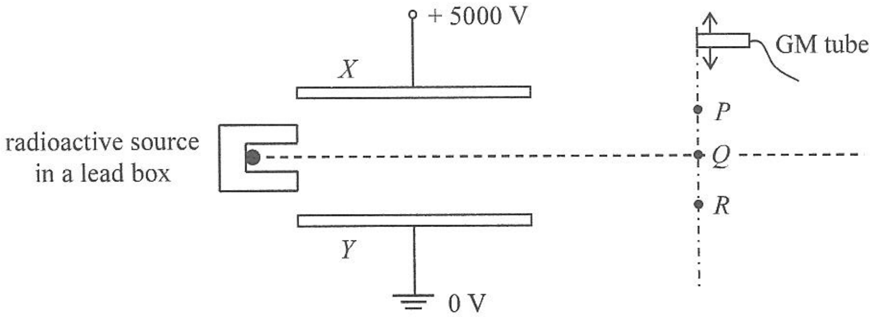
D.



M53. The initial activity of a sample of radioisotope is 960 Bq. Its activity drops to 240 Bq in 2 minutes. How much more time
(10) would be required for its activity to become 30 Bq ?

A. 2 minutes
B. 3 minutes
C. 4 minutes
D. 5 minutes

M54.
(11)



The figure shows a radioactive source placed near two parallel metal plates X and Y that are connected to a power supply. When a GM tube is moved along the dotted line (– · – · –), the count rate shows a significant increase at P and Q respectively. Which of the following statements is correct when a magnetic field pointing out of paper is applied between X and Y ?

A. The count rate at P decreases and the count rate at Q remains the same.
B. The count rates at P and Q remain the same.
C. The count rate at P decreases and the count rates at Q and R increase.
D. The count rates at P, Q and R are equal.

M55. Which of the following statements about α, β and γ radiations is **incorrect** ?
(11) A. Only γ radiation can travel through a vacuum.
B. α radiation can be stopped by an aluminium plate of 5 mm thick.
C. β particles are fast moving electrons.
D. γ radiation can blacken a photographic film.

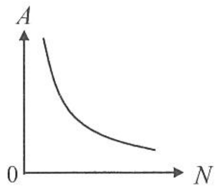
M56. A radioactive source is put in front of a GM tube. The initial count rate is 1050 counts per minute. It is known that the
(11) half-life of the source is 4 hours and the background count rate is 50 counts per minute. What is the most likely count rate (in counts per minute) after 8 hours ?
A. 50
B. 125
C. 250
D. 300

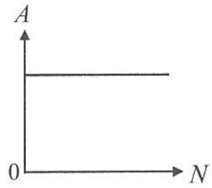
Part C :

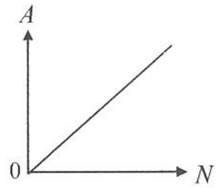
The following questions marked with [ ] are the past HKAL questions.

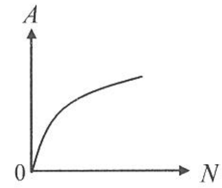
The number inside the brackets represents the year of the examination.

M57. Which of the graphs below correctly represents the variation of the activity A of a radioactive sample with the number N of
[80] undecayed nuclei in the sample ?

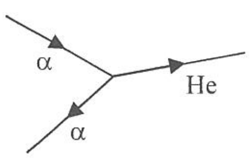
A.


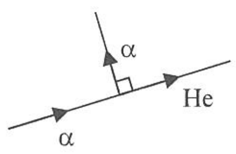
B.


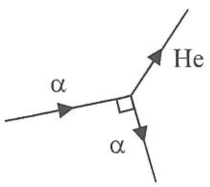
C.


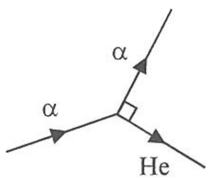
D.


M58. An alpha particle collides with a stationary helium nucleus (He) in a cloud chamber. Which of the following diagrams best
[84] represents the most probable set of tracks ?

A.


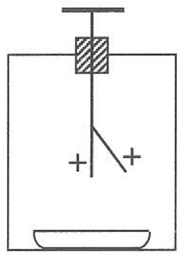
B.


C.


D.


M59. Proactinium extracted from a solution of uranyl nitrate decays with a half-life of 72 s. The value of the decay constant is
[85] A. 9.6×10^{-3} s.
B. $9.6 \times 10^{-3}\ s^{-1}$.
C. $0.014\ s^{-1}$.
D. 49.9 s.

M60.
[85]



A dish containing a strong α-source is placed inside a gold leaf electroscope containing dry air. If the gold-leaf is originally positively charged, what will happen to it after a few minutes ?

A. It will increase in divergence.

B. It will increase in divergence and then decrease.

C. It will collapse.

D. It will collapse and then re-diverge.

M61. [88] An α-source originally consisted entirely of the element polonium. After the emission of a single α-particle, each polonium atom becomes an atom of lead. At the end of two years, the source was found to contain 98% lead and 2% polonium. At the end of one year, the sample would have had the approximate composition :

A. 25% lead, 75% polonium.

B. 50% lead, 50% polonium.

C. 75% lead, 25% polonium.

D. 86% lead, 14% polonium.

M62. [90] A radioactive source is placed in front of a GM tube connected to a counter. Various absorbers are placed between the source and the GM tube and the count-rate recorded. The following results were obtained :

Absorber	Counts per minute
no absorber	711
a sheet of paper	508
5 mm thick aluminium sheet	493
25 mm thick lead block	218

It can be deduced from these results that the radiation(s) emitted by the source is/are

A. α and γ rays only

B. β and γ rays only

C. α rays only

D. β rays only

M63. [92] A radioactive source consists of a mixture of two radioisotopes P and Q. P has a half-life of 1 hour and Q has a half-life of 2 hours. Both P and Q have stable daughter nuclei. The initial corrected count rate due to the mixture recorded by a counter is 600 counts per min. After 4 hours the counter registers the corrected count rate of 60 counts per min. What was the initial count rate due to P only ?

A. 200 counts per min.

B. 360 counts per min.

C. 400 counts per min.

D. 480 counts per min.

M64. [94] A detector is used for monitoring an α-source and a reading of 120 units is observed. After a time equal to the half-life of the α-source, the reading has fallen to 64 units. If a 5 mm thick lead sheet is inserted between the α-source and the detector, the reading would probably be

A. 0 unit

B. 4 units

C. 8 units

D. 16 units

M65. A counter is placed near a very weak radioactive source which has a half-life of 1 hour. The counter registers 100 counts per
[96] min at noon and 80 counts per min at 1 p.m. The expected count rate in counts per min at 3 p.m. on the same day is

A. 50
B. 55
C. 60
D. 65

M66. The activity of a sample of radioactive isotopes decreases to $\frac{1}{3}$ of its initial value in 12 s. How much more time would be
[98] required for the activity to decrease to $\frac{1}{9}$ of its initial value ?

A. 4 s
B. 8 s
C. 12 s
D. 16 s

M67. A GM counter is placed close to and in front of a radioactive source which emits both α and γ radiation. The count rate
[00] recorded is 500 counts per minute while the background count rate is 50 counts per minute. Three different materials are placed **in turn** between the source and the counter. The following results are obtained.

Material	Recorded count rate / counts per minute
(Nil)	500
Cardboard	x
1 mm of aluminium	y
5 mm of lead	z

Which of the following is a suitable set of values for x, y and z ?

	x	y	z
A.	350	350	150
B.	350	150	50
C.	350	150	0
D.	150	150	50

M68. The table below gives the corrected count rate (in counts per minute) from three samples of radioactive isotopes at three
[01] different times.

Isotopes	0 min	20 min	40 min
X	480	243	119
Y	135	32	9
Z	168	118	93

The above data show that

(1) X produces the most penetrating radiation.

(2) Y has the largest decay constant.

(3) Z has the longest half-life.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M69. The activity of a radioactive sample was 70 Bq at time t = 5 minutes and 49 Bq at t = 10 minutes. Deduce its activity at
[01] time t = 0.

A. 112 Bq
B. 100 Bq
C. 95 Bq
D. 91 Bq

M70. A nuclide in radioactive sample has a constant chance of 10^{-6} to decay in one second. What is the **approximate** half-life of
[03] the sample ?

A. 1 day
B. 1 week
C. 1 month
D. 1 year

M71. The activity of a freshly prepared sample of ^{60}Co is 1.0×10^6 Bq. The half-life of ^{60}Co is 5.3 years. Estimate the number of
[04] ^{60}Co nuclei in the sample that decay in the first day.

A. 5.2×10^2
B. 3.2×10^8
C. 8.6×10^{10}
D. It cannot be estimated as the initial number of nuclei in the sample is not given.

M72. On which of the following does the activity of a radioactive source depend ?
[05]
(1) the number of active nuclei in the source
(2) the half-life of the source
(3) the nature of the nuclear radiation emitted by the source

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M73. Some typical radiation doses are tabulated as follows :
[06]

	Radiation dose
Watching television	0.005 mSv / hr for watching every day in a year
Flying in an aircraft	0.001 mSv / hr
X-ray check	0.020 mSv each time

Arrange the following in ascending order of total radiation dose in one year.

(1) Watching television for 4 hours every day
(2) Travelling on an aircraft for 10 hours every month
(3) Taking X-ray check every 6 months

A. (1), (2), (3)
B. (2), (1), (3)
C. (1), (3), (2)
D. (3), (1), (2)

M74. Which of the following gives the correct meaning of the decay constant of a radioactive substance ?

[06] A. It is the rate of disintegrations of the substance.

B. It is the number of disintegrations of the substance occurring on one half-life of the substance.

C. It is the fraction of the active nuclei present that decay in one second.

D. It is equal to the reciprocal of the half-life of the substance.

M75. A radioactive source consists of 64×10^{12} atoms of nuclide P of half-life 2 days. Another source consists of 8×10^{12} atoms
[07] of nuclide Q of half-life 3 days. After how long will the number of active nuclei in the two sources be equal ?
(Assume that the daughter nuclides of both P and Q are stable.)

A. 6 days
B. 9 days
C. 12 days
D. 18 days

M76. Radioactive nuclides X and Y have half-lives 2 hours and 4 hours respectively. The decay of both nuclides gives stable
[11] daughters. Initially samples P and Q contain equal number of atoms of nuclide X and nuclide Y respectively. Which statements are correct ?

(1) The initial activity of sample P is higher than that of sample Q.

(2) After 8 hours, sample P contains more active nuclei than sample Q.

(3) After 8 hours, the chance of a nucleus of X in sample P decaying in the next minute is greater than that of a nucleus of Y in sample Q.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

M77. The activity of a radioisotope is 250 Bq at time $t = 0$ and 54 Bq at $t = 30$ min. Estimate its activity at $t = 10$ min.

[12] A. 130 Bq

B. 150 Bq

C. 185 Bq

D. It cannot be found as its half-life is not given.

M78. Arrange the following lengths in ascending order of magnitudes.

[13] (1) range of α-particles in air

(2) grating spacing of a typical diffraction grating in a school laboratory

(3) wavelength of ultra-violet radiation

A. (1), (2), (3)
B. (1), (3), (2)
C. (3), (1), (2)
D. (3), (2), (1)

M79. The initial activity of two different radioactive sources, X and Y, are the same. Both X and Y decay to stable daughter nuclei.
[13] The ratio of the activity of X to that of Y after 12 hours is 4 : 1. If X has a half-life of 6 hours, what is the half-life of Y ?

A. 1.5 hours

B. 2 hours

C. 3 hours

D. 12 hours

Answers

1. D	11. D	21. B	31. A	41. C	51. D	61. D	71. C
2. C	12. D	22. C	32. A	42. C	52. C	62. A	72. C
3. C	13. A	23. B	33. D	43. B	53. B	63. D	73. C
4. B	14. D	24. B	34. C	44. C	54. A	64. C	74. C
5. C	15. C	25. D	35. D	45. A	55. A	65. D	75. D
6. C	16. D	26. D	36. D	46. C	56. D	66. C	76. B
7. B	17. C	27. D	37. D	47. D	57. C	67. A	77. B
8. A	18. B	28. D	38. D	48. D	58. D	68. D	78. D
9. A	19. C	29. C	39. C	49. B	59. B	69. B	79. C
10. B	20. C	30. D	40. B	50. D	60. C	70. B	

Solution

1. D

× (1) The nature or type of radiation (α, β, γ) emitted would not affect or relate to the activity of the source.

✓ (2) The activity A is proportional to the decay constant k, which is related by the half-life.

✓ (3) The activity A is proportional to the number of active (undecayed) nuclei N.

2. C

After inserting the paper, the count rate is approximately unchanged, thus the source does not emit α.

After inserting the 5 mm Al, the count rate drops significantly, thus the source emits β.

After inserting the lead, the count rate drops significantly, thus the source emits γ.

3. C

✓ (1) The mass of an α particle is the mass of a helium nucleus but the mass of a β particle is nearly zero.

× (2) The penetrating power of α is weaker than β.

✓ (3) α particles can ionize the air, the ions then discharge the charged metal sphere.

4. B

× A. Since there is no count rate recorded at positions above X, the source may or may not emit α radiations.

✓ B. Since the count rate at Y is greater than X, there must be some radiation deflected downwards to reach Y. By Left hand rule, the downward magnetic force should act on negative particles, that is, β radiations.

× C. The source may or may not emit γ radiation,
as the count rate at X may consist of γ and background or background only

× D. The source may emit γ radiation, thus the count rate of 101 cpm at X may be due to γ and background.

5. C

$N = N_o\,(\frac{1}{2})^{10/20} = 0.707\,N_o$

$f = \dfrac{N}{N_o} = 0.707$

$\therefore\ 0.75 > f > 0.5$

6. C

Cathode rays (beam of electrons) is emitted from *F* which is the negative terminal, thus *Q* is the positive terminal.

When electrons hit the metal target at *T*, X-rays are emitted from *T*.

7. B

$m = m_o\,(\dfrac{1}{2})^{t/t_{1/2}} = (420)\,(\dfrac{1}{2})^{70/140} = 297\text{ mg}$

8. A

Note that γ radiation can never be totally absorbed.

Thus, *z* must be greater than the background radiation of 50 counts per minute.

The only option is A that *z* is 100 counts per minute.

9. A

α-radiation cannot pass through the plastic bag to reach the film, thus α-radiation cannot be detected.

The other 3 types of radiation can pass the plastic bag to reach the film inside the badge to be detected.

10. B

Mass of X: $4 \xrightarrow{\text{3 days}} 2 \xrightarrow{\text{3 days}} 1$

Mass of Y: $4 - 1 = 3$ g

11. D

Ionization power : $\alpha > \beta > \gamma$

In ascending order : γ , β , α

12. D

× (1) Decay does not mean splitting of the atoms.

× (2) In 20 minutes, that is, 2 half-lives, there is still 25% of radioactive atoms left.

× (3) Half-life is the time taken for half of the number of radioactive atoms to decay.

13. A

$3 \xrightarrow{\text{8 hours}} 1.5 \xrightarrow{\text{8 hours}} 0.75 \xrightarrow{\text{8 hours}} 0.375$

After 24 hours, the mass remaining unchanged is 0.375 g

14. D

By using Left-hand rule :

Direction of magnetic field is into paper and direction of magnetic force is downward $\Rightarrow$ Direction of I is towards the left

As direction of I is opposite to velocity $\Rightarrow$ the radiation carries (–) charge $\Rightarrow$ β radiation

15. C

Corrected count rate : $0.8 \longrightarrow 0.4 \longrightarrow 0.2$

As in between July 1 and September 1, there is 62 days.

$\therefore$ Half-life $= \dfrac{62}{2} = 31$ days

16. D

X-ray and γ-ray are both electromagnetic waves

$\therefore$ they travel with the speed of light

β-particles are fast moving electrons, but not electromagnetic waves.

β-particles travel with a speed less than that of light.

17. C

✓ (1) α-particle is ${}^{4}_{2}\text{He}$ nucleus while hydrogen atom is ${}^{1}_{1}\text{H}$.

✓ (2) ionizing power : $\alpha > \beta > \gamma$

× (3) α-particles have shortest range in air $\Rightarrow$ weakest penetrating power

18. B

× (1) The product of decay also carries mass, thus the total mass of the sample should remain unchanged.

✓ (2) Half-life is the time taken for the activity to drop to half of the initial value.

× (3) It takes 1 half-life for half of the number **of undecayed n**uclei to decay,
but it does not mean another half is to be decayed in the next half-life.

19. C

$$1 \longrightarrow \frac{1}{2} \longrightarrow \frac{1}{4} \longrightarrow \frac{1}{8}$$

$\therefore$ Half-life $= \dfrac{24}{3} = 8$ min.

20. C

$$1 \xrightarrow{\text{22 years}} \frac{1}{2} \xrightarrow{\text{22 years}} \frac{1}{4} \xrightarrow{\text{22 years}} \frac{1}{8}$$

After 66 years, the fraction of the source remains undecayed is $\dfrac{1}{8}$

21. B

Time / minute	0	2	4	6	8	10	12
Corrected count rate / cpm	96	76	60	49	38	30	24

As the initial corrected count rate (96 cpm) reduces to about half (48 cpm) in 6 minutes

∴ half-life is about 6 minutes.

22. C

As activity drops from 40 Bq to 20 Bq in 28 minutes

∴ half-life = 28 min

23. B

By using Left-hand rule :

① magnetic force on α which is positive is towards the left

② magnetic force on β which is negative is towards the right

Thus, α is deflected to the left while β is deflected to the right.

As α is much heavier, the degree of deflection of α is much smaller than that of β.

24. B

It is a symbol for all types of radioactive substances.

25. D

Ionizing power : $\gamma < \beta < \alpha$

26. D

$640 \xrightarrow{\times\frac{1}{2}} 320 \xrightarrow{\times\frac{1}{2}} 160 \xrightarrow{\times\frac{1}{2}} 80 \xrightarrow{\times\frac{1}{2}} 40$

$\therefore$ Half-life $= \dfrac{2 \text{ hours}}{4} = 0.5$ hours $= 30$ min.

27. D

✓ A. β-particles are particles that can travel in vacuum

✓ B. Infra-red is a type of electromagnetic waves that can travel in vacuum

✓ C. Microwave is a type of electromagnetic waves that can travel in vacuum

✗ D. Ultrasonics are sound waves with frequency > 20000 Hz, sound waves cannot travel in vacuum.

28. D

✗ (1) X-rays is a transverse wave, they do not consist of any particles.

✓ (2) X-rays can affect films, and be detected by films.

✓ (3) X-rays are used in airport to detect weapons in luggage.

29. C

Charged particles can be deflected by both a magnetic field and an electric field.

α is (+)-charged and β is (–)-charged, they can be deflected; γ is neutral, it cannot be deflected.

30. D

$$1 \xrightarrow{\times\frac{1}{2}} \frac{1}{2} \xrightarrow{\times\frac{1}{2}} \frac{1}{4} \xrightarrow{\times\frac{1}{2}} \frac{1}{8} \xrightarrow{\times\frac{1}{2}} \frac{1}{16} \qquad \therefore \text{Half-life} = \frac{60}{4} = 15 \text{ min.}$$

31. A

- ✗ A. β particles can penetrate through paper but stopped by a thin sheet of aluminium.
- ✓ B. β particles are (–)-charged particles $\Rightarrow$ deflected by B-field
- ✓ C. β particles are radiation, they can blacken films and be detected.
- ✓ D. β are particles, thus they can travel in vacuum.

32. A

By using Left hand rule to find the magnetic force on the moving charged particles.

α is (+) charged and is deflected towards the right

β is (–) charged and is deflected towards the left

Since β is lighter than α, thus the deflection of β is greater.

33. D

- ✓ A. α-particles have a very low penetrating power in matter, they are stopped by a piece of paper.
- ✓ B. α-particles are radiation that can blacken films.
- ✓ C. α-particles have a very short range in air, about several centimeters.
- ✗ D. α are particles, they can travel in vacuum.

34. C

- ✓ (1) α-source emits α-particles that can ionize air molecules to give ion-pairs.
  The ion-pairs can discharge sphere.
- ✓ (2) Touching the sphere with a finger is an Earthing process that can discharge the sphere.
- ✗ (3) Since the rod does not touch the sphere,
  there is no flow of charge and does the charge in the sphere remains the same

35. D

Corrected count rate initially $= 560 - 80 = 480$ counts per minute

Corrected count rate after 6 hours $= 140 - 80 = 60$ counts per minute

Change of corrected count rate after each half-life :

$$480 \longrightarrow 240 \longrightarrow 120 \longrightarrow 60$$

$$\therefore \text{Half-life} = \frac{6}{3} = 2 \text{ hours}$$

36. D

× A. α : not a wave

× B. γ : do not have charge $\Rightarrow$ cannot be deflected by B-field

× C. γ : weak ionization power

✓ D. α : particles can travel in vacuum ; γ : electromagnetic waves can also travel in vacuum.

37. D

Radioactive sources should be stored in **lead** castles but not a wooden box only
since lead is the most effective material to stop the radiations

38. D

Activity : $2000 \longrightarrow 1000 \longrightarrow 500 \longrightarrow 250 \longrightarrow 125$

Number of half-lives = 4

Half-life = 4 hours × $\frac{1}{4}$ = 1 hour = 60 minutes

39. C

Neutrons are neutral particles.
They would not be deflected by magnetic field or electric field.

40. B

× (1) α particles carry positive charges, they can be deflected by a magnetic field.
γ rays are neutral, they cannot be deflected by a magnetic field.

✓ (2) The ionizing power in descending order is $\alpha > \beta > \gamma$

× (3) The speed of α particles is less than the speed of light wave in air
but γ rays have the same speed as the light wave in air

41. C

The half-life of P is 10 minutes.
The half-life of Q is 5 minutes, thus after 10 minutes, the activity of Q drops to one quarter.
Ratio of the half-life of P to that of Q = 10 : 5 = 2 : 1

42. C

After inserting the paper, the count rate is approximately unchanged, thus the source does not emit α.
After inserting the 5 mm Al, the count rate drops significantly, thus the source emits β.
After inserting the lead, the count rate drops significantly, thus the source emits γ.

43. B

P detects γ radiation since γ does not deflect in magnetic field
Q detects β radiation since magnetic force acts downwards on negative charged particles by using Left hand rule.

44. C

$X: \ N \xrightarrow{\text{2 days}} \frac{1}{2}N \xrightarrow{\text{2 days}} \frac{1}{4}N \xrightarrow{\text{2 days}} \frac{1}{8}N$

$Y: \ 8N \xrightarrow{\text{1 days}} 4N \xrightarrow{\text{1 days}} 2N \xrightarrow{\text{1 days}} N \xrightarrow{\text{1 days}} \frac{1}{2}N \xrightarrow{\text{1 days}} \frac{1}{4}N \xrightarrow{\text{1 days}} \frac{1}{8}N$

After 6 days, both X and Y have the same number of undecayed atoms of $\frac{1}{8}N$

45. A

From the graph, the background radiation is 50.

The initial total count rate is 350, thus the initial corrected count rate is 350 – 50 = 300.

After one half-life, the corrected count rate should drop to 150, thus the total count rate is 150 + 50 = 200.

The total count rate drops to 200 after 4 minutes, thus the half-life is 4 minutes.

46. C

Lead is the suitable metal to be used in the container since most radiation can be blocked by lead.

The symbol represents RADIOACTIVE substance.

47. D

×	A.	Time for all the radioactive nuclei to decay is infinite, half of this time is also infinite.
×	B.	Time for a radioactive nucleus to decay is random.
×	C.	Mass of the sample remains unchanged since the sample includes the mother nuclei and daughter nuclei..
✓	D.	Time for half of the radioactive nuclei to decay is the definition of half-life.

48. D

×	A.	The person still receives the background radiation only, no extra radiation is received.
×	B.	Food that has been sterilized by exposure to gamma radiation does not have radiation remain.
×	C.	Listening to radio does not receive any radiation.
✓	D.	Passengers in high-flying aeroplane receive greater amount of cosmic radiation.

49. B

×	A.	β particles carry negative charge since they are electrons.
✓	B.	β particles can be deflected by a magnetic field, direction of deflection is found by Left hand rule.
×	C.	β particles can be deflected by an electric field, towards the positive plate.
×	D.	β particles can penetrate through sheets of paper, they can be stopped by aluminium.

50. D

Assume that the background count rate is b counts per minute.

After one half-life, the corrected count rate is reduced to half.

$\therefore \ (1000 - b) \times \frac{1}{2} = (528 - b)$

$\therefore \ b = 56$

51. D

By Left hand rule, the magnetic force is pointing downwards.
In order to balance the magnetic force, the electric force should be pointing upwards.
Since the electric force is opposite to the electric field for a negative charge, the β particle,
thus the electric field is pointing downwards.

52. C

After a period of time, both the balls P and Q are discharged by the ions produced by the α particles.
Thus, the two neutral balls would not exert forces on each other.

53. B

① $(240) = (960)\ (\frac{1}{2})^{2/t_{1/2}}$ $\therefore\ t_{1/2} = 1$ min.

② $(30) = (240)\ (\frac{1}{2})^{t/1}$ $\therefore\ t = 3$ min.

OR

① $(240) = (960)\ e^{-k(2)}$ $\therefore\ k = 0.693\ \text{min}^{-1}$

② $(30) = (240)\ e^{-0.693\,t}$ $\therefore\ t = 3$ min

54. A

At P, the radiation is β since it is attracted upwards towards the positive side of the electric field.
At Q, the radiation is γ since it is not deflected by the electric field.
After applying the magnetic field, the magnetic force acting on β is upwards, thus the count rate at P decreases.
As the radiation at Q is γ which is not affected by magnetic field, the count rate at Q is the same.

55. A

× A. All the three types of nuclear radiations can travel through a vacuum.

✓ B. α radiation can be stopped by a piece of paper, and also by a thicker piece of aluminium.

✓ C. β particles are electrons moving with high speed.

✓ D. All the three types of nuclear radiations, including γ, can blacken a photographic film.

56. D

Initial corrected count rate $= 1050 - 50 = 1000$ counts per minute

Number of half-life period $= 8 / 4 = 2$

Corrected count rate after 8 hours $= 1000 \times (\frac{1}{2})^2 = 250$ counts per minute

Count rate after 8 hours $= 250 + 50 = 300$ counts per minute

57. C

By $A = kN$ $\therefore$ $A \propto N$, activity is directly proportional to the number of undecayed nuclei.

The graph is a straight line passing through the origin.

58. D

After colliding with a helium nucleus, the angle of separation between the alpha particle and the helium nucleus is 90°.

Option B is not correct as the collision does not obey the conservation of momentum.

59. B

$$k = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{\ln 2}{(72)} = 9.6\times10^{-3}\ \text{s}^{-1}$$

60. C

As the alpha particles would ionize the air, the ions then discharge the gold-leaf,
thus the gold-leaf would collapse.

61. D

At the end of 2 years, there is 2% Polonium remaining, thus

$(2\%) = (100\%)\, e^{-k(2)} \qquad \therefore\ k = 1.96\ \text{year}^{-1}$

At the end of 1 year : $N = N_o\, e^{-(1.96)(1)} = 0.14\, N_o$

$\therefore$ There is 14% of Polonium and 86% of Lead.

62. A

Presence of paper : shows a significant drop in counts per minute $\Rightarrow$ the source emits α-rays

Presence of Al : shows a slight change in counts per minute $\Rightarrow$ the source does not emit β-rays

Presence of Pb block : shows a significant drop in counts per minute $\Rightarrow$ the source emits γ-rays

63. D

Let x be the initial count rate of P, then $(600-x)$ is the initial count rate of Q.

$$P:\ x \xrightarrow{\text{1 hour}} \frac{x}{2} \xrightarrow{\text{1 hour}} \frac{x}{4} \xrightarrow{\text{1 hour}} \frac{x}{8} \xrightarrow{\text{1 hour}} \frac{x}{16}$$

$$Q:\ (600-x) \xrightarrow{\text{2 hours}} \frac{600-x}{2} \xrightarrow{\text{2 hours}} \frac{600-x}{4}$$

After 4 hours : $\dfrac{x}{16} + \dfrac{600-x}{4} = 60 \qquad \therefore\ x = 480$ cpm

64. C

Let b be the background radiation.

After one half-life, the corrected count rate is reduced to half.

$(120 - b) \times \frac{1}{2} = (64 - b)$

$\therefore\ b = 8$

After inserting the lead sheet, all the α particles would be absorbed.

Thus, the detector can then only measure the background radiation, which is 8 units.

65. D

Let b be the background radiation.

$\frac{1}{2}(100 - b) + b = 80$ $\therefore\ b = 60$ cpm

$\therefore$ Activity of the source at noon = 100 – 60 = 40 cpm

After 3 hours, activity : $40 \xrightarrow{1\text{ hour}} 20 \xrightarrow{1\text{ hour}} 10 \xrightarrow{1\text{ hour}} 5$

$\therefore$ Expected count rate = 60 + 5 = 65 cpm

66. C

When the activity drops to $\frac{1}{3}$ of its initial value : $\left(\frac{1}{3}A\right) = A \cdot e^{-k(12)}$ $\therefore\ k = 0.0916\ \text{s}^{-1}$

When the activity drops to $\frac{1}{9}$ of its initial value : $\left(\frac{1}{9}A\right) = A \cdot e^{-(0.0916)(t+12)}$ $\therefore\ t = 12$ s

67. A

Cardboard : Due to the absorption of α-radiation, the count rate should drop.

1 mm of Al : Since there is no β-radiation, the count rate should remain the same as x.

5 mm of Pb : The count rate should drop due to the partial absorption of γ-radiation.
However, the lead would not absorb all the γ-radiation, thus the count rate cannot drop to 50 cpm.
Thus, the value of z should be 150.

68. D

✗ (1) Type of radiation cannot be known from the count rate at different times

✓ (2) Y has the shortest half-life since after 20 minutes it drops to about $\frac{1}{4}$

By decay constant $k = \dfrac{\ell n\, 2}{t_{1/2}}$ $\therefore$ Y has the largest decay constant

✓ (3) Z has the longest half-life since after 20 minutes it drops only to about 70 %

69. B

By $A = A_o\, e^{-kt}$

① $(70) = A_o\, e^{-k(5)}$

② $(49) = A_o\, e^{-k(10)}$

$\therefore\ \dfrac{70}{49} = e^{5k}$ $\therefore\ k = 0.0713$ $\therefore\ A_o = 100$ Bq

70. B

The decay constant k is the chance of decay per unit time.

$\therefore\ k = 10^{-6}\ \text{s}^{-1}$

Half-life $= \dfrac{\ln 2}{k} = \dfrac{\ln 2}{10^{-6}} = 6.93 \times 10^5$ s $= 8$ days ≈ 1 week

71. C

Since the time of 1 day is much less than the half-life of 5.3 years, activity remains constant in 1 day.

$\Delta N = A\,\Delta t = (1.0 \times 10^6) \times (1 \times 24 \times 3600) = 8.6 \times 10^{10}$

OR

$$k = \frac{\ln 2}{5.3 \times 365 \times 24 \times 3600} = 4.147 \times 10^{-9}\ \text{s}^{-1}$$

By $A_o = k N_o$ $\therefore$ $(1.0 \times 10^6) = (4.147 \times 10^{-9}) N_o$ $\therefore$ $N_o = 2.41138 \times 10^{14}$

By $N = N_o \cdot e^{-k \cdot t}$ $\therefore$ $N = (2.41138 \times 10^{14}) \cdot e^{-(4.147 \times 10^{-9}) \cdot (1 \times 24 \times 3600)} = 2.41052 \times 10^{14}$

$\Delta N = 2.41138 \times 10^{14} - 2.41052 \times 10^{14} = 8.6 \times 10^{10}$

72. C

By $A = kN$ $\therefore$ Activity A depends on

① decay constant k or half-life $t_{1/2}$

② number of undecayed nuclei N in the source

By $t_{\frac{1}{2}} = \dfrac{\ln 2}{k}$, decay constant k is related to the half-life.

73. C

(1) Radiation dose of watching television for 4 hours every day = 0.005 mSv/hr × 4 hr = 0.02 mSv

(2) Radiation dose of flying in an aircraft = 0.001 mSv/hr × 10 h/month × 12 months = 0.12 mSv

(3) Radiation dose of X-ray check = 0.020 mSv × 2 = 0.04 mSv

Ascending order of total radiation dose : (1), (3), (2)

74. C

Decay constant is the probability of decay per unit time,
it means the fraction of the active nuclei present that decay in one second.

75. D

For nuclide P : $64 \rightarrow 32 \rightarrow 16 \rightarrow 8 \rightarrow 4 \rightarrow 2 \rightarrow 1 \rightarrow \frac{1}{2} \rightarrow \frac{1}{4} \rightarrow \frac{1}{8}$: time taken = 2 × 9 = 18 days

For nuclide Q : $8 \rightarrow 4 \rightarrow 2 \rightarrow 1 \rightarrow \frac{1}{2} \rightarrow \frac{1}{4} \rightarrow \frac{1}{8}$: time taken = 3 × 6 = 18 days

76. B

✓ (1) By $k = \ln 2 / t_{1/2}$, X has shorter half-life, thus X has greater decay constant k.
By $A = kN$, X has greater decay constant k, thus the activity of X in sample P is higher.

× (2) After 8 hours, the number of X in P drops to 1/16 and the number of Y in Q drops to 1/4.
Thus the number of X in sample P is less.

✓ (3) The chance of decay in unit time is the decay constant.
As the decay constant of X is greater, the chance is also greater.

77. B

By $A = A_o \, e^{-kt}$

$\therefore \ (54) = (250)\, e^{-k(30)}$

$\therefore \ k = 0.0511 \text{ min}^{-1}$

At $t = 10$ min. : $A = (250)\, e^{-(0.0511)(10)} = 150$ Bq

78. D

(3) wavelength of ultra-violet radiation is of the order of 10^{-8} m

(2) grating spacing is of the order of 10^{-6} m

(1) range of α in air is of the order of 10^{-2} m (a few cm)

79. C

For X : 12 hours is two half-lives $\therefore \ A_X = A_o \times (\frac{1}{2})^2 = \frac{1}{4} A_o$

After 12 hours,

$A_X : A_Y = 4 : 1$

$\therefore \ A_Y = \frac{1}{4} A_X = \frac{1}{4} \times (\frac{1}{4} A_o) = \frac{1}{16} A_o$

For Y : $A = A_o (\frac{1}{2})^{t / t_{1/2}}$

$\therefore \ (\frac{1}{16} A_o) = A_o (\frac{1}{2})^{(12) / t_{1/2}}$ $\qquad \therefore \ t_{1/2} = 3$

$\therefore$ half-life of Y = 3 hours

The following list of formulae may be found useful :

Law of radioactive decay	$N = N_0 e^{-kt}$
Half-life and decay constant	$t_{\frac{1}{2}} = \dfrac{\ln 2}{k}$
Activity and the number of undecayed nuclei	$A = kN$

Part A :

The following questions marked with { } are the past DSE examination questions.

The question marked with {PP} is the Practice Paper question.

The number inside the brackets represents the year of the DSE examination.

Q1. {PP} The decay of radioactive isotope protactinium-238 (^{238}Pa) has a half-life of approximately 136 s. A sample of ^{238}Pa is put in front of a GM tube and the initial count rate is 1000 counts per minute. The background count rate is 50 counts per minute.

(a) It is known that the decay of ^{238}Pa does not emit γ radiation. Suggest a simple test to verify the radiation from ^{238}Pa is β radiation but not α radiation. (3 marks)

(b) Estimate the decay constant of ^{238}Pa. (1 mark)

(c) Hence, or otherwise, estimate the time taken for the count rate to drop to 250 counts per minute. (3 marks)

Q2. {14} *Voyager I* is a space probe designed by NASA to operate for over ten years in space. It was equipped with a radioisotope thermoelectric generator (RTG) which can convert the energy released from the decay of a radioactive source into electrical power. *Voyage I* operates with a plutonium-238 radioactive source that undergoes α-decay.

(a) The plutonium-238 source is sealed inside a thin metallic casing of the RTG. The photo shows a NASA staff handling the RTG with his bare hands. Explain why it is fine for it to be handled by the staff in this way. (1 mark)

When *Voyager I* was launched, the number of plutonium-238 atoms in the source was 3.2×10^{25}.

Given : half-life of plutonium-238 = 87.74 years.

Take 1 year = 3.16×10^{7} s.

(b) (i) Find the activity, in Bq, of the plutonium source at the time of launch. (3 marks)

(ii) When a plutonium-238 atom decays, it releases 5.5 MeV of energy. Estimate the power, in kW, delivered by the source at the time of launch. (2 marks)

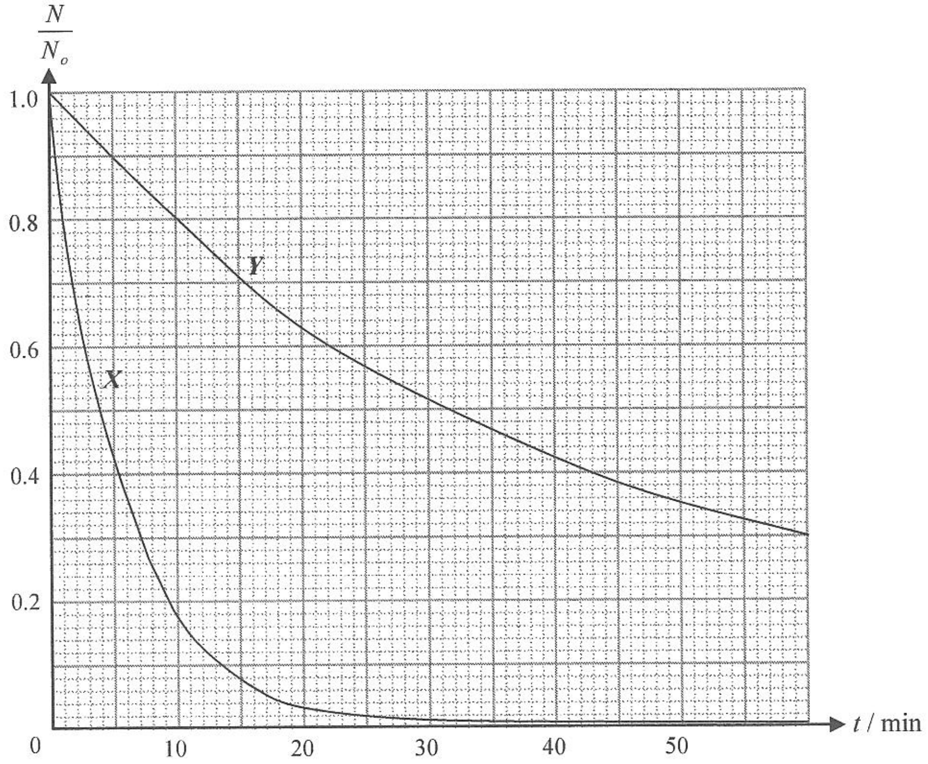
(iii) The RTG of *Voyage I* is still in operation as *Voyage I* just left the solar system in September 2013 after it was launched 36 years ago. Estimate the corresponding power delivered by the plutonium source, expressed in percentage of the power delivered at the time of launch. (2 marks)

Part B :

The following questions marked with ( ) are the past HKCE questions.

The number inside the brackets represents the year of the examination.

Q3.
(82)



The above figure show the decay curves of two radioactive elements X and Y both emitting β-particles. N_o is the number of radioactive atoms present at time $t = 0$ and N is the number at the end of t minutes.

(a) What are the half-lives of X and Y ? (2 marks)

(b) A mixture of X and Y is placed in front of a Geiger counter. Initially, they have the same number of radioactive atoms. Which of the two, X or Y, will be mainly responsible for the reading shown on the Geiger counter during the first four minutes ? Estimate the fraction of the total number of counts due to that element. (5 marks)

Q4. The activity from a sample of Radium is measured at two-day intervals. The readings are tabulated below :
(83)

Time / days	0	2	4	6	8	10
Activity / Bq	100	68	47	32	22	15

(a) Plot the decay graph below to show the activity against time. (4 marks)

(b) From the graph, find (2 marks)

(i) the activity of the sample after 5 days, and

(ii) the half-life of the sample.

Q5. A Geiger-Muller counter is placed on a bench.
(83)

(a) Explain why the counter registers a reading even when no radioactive source is placed nearby. (1 mark)

____

____

(b) When a radioactive source is placed near the counter, the counter registers 520, 510 and 514 counts per minute in the first three consecutive minutes. Explain why the three readings differ from each other ? (2 marks)

____

____

(c) When a piece of paper is placed between the source in (ii) and the counter, the counter registers 540, 510 and 512 counts per minute in the first three consecutive minutes. However, when the paper is replaced by an aluminium sheet, the counts are reduced to 7, 9 and 8 respectively.

What type(s) of radiation (α, β or γ) is/are being emitted by the source ? Give a reason for your answer. (4 marks)

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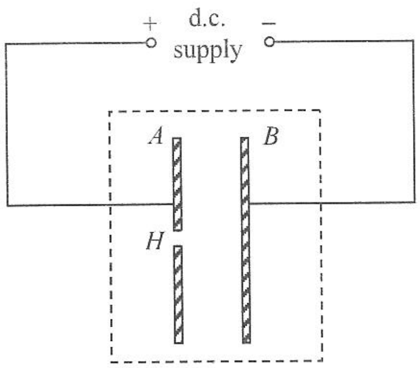
____

Q6. Two parallel metal plates A and B are placed in a vacuum chamber as shown in the figure below. They are connected to a
(84) d.c. supply. A hole H is drilled in plate A. A particle P passes through hole H and accelerates towards plate B.



(a) What is the sign of the charge carried by P ? (1 mark)

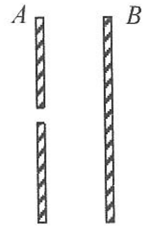
____

(b) The particle P is emitted from a radioactive source which undergoes α-, β- and γ-decay simultaneously.

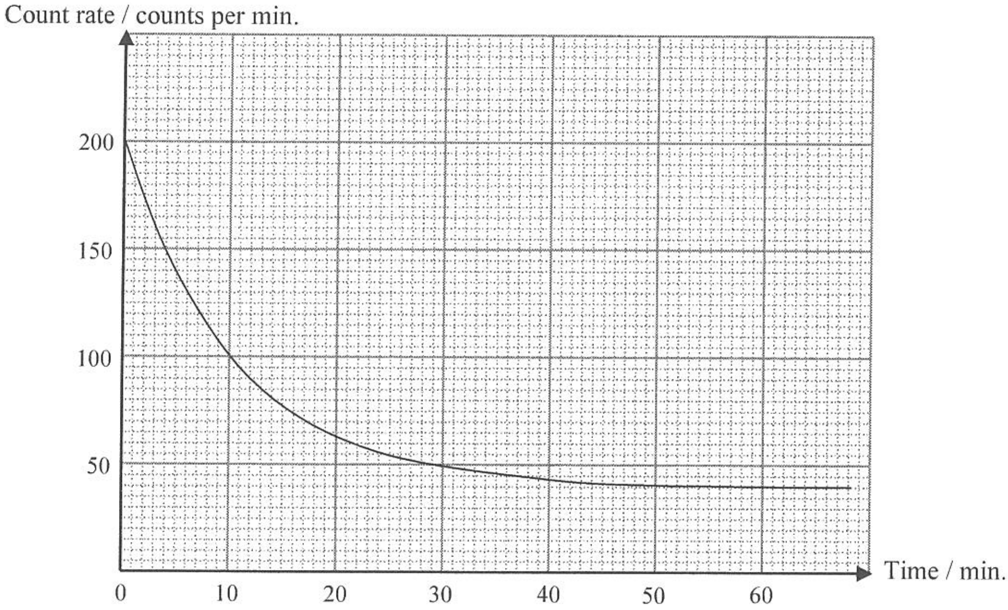
(i) What kind of particle (α, β or γ) should P be ? (1 mark)

____

(ii) Draw a diagram to show how to prevent the other two kinds of particles from reaching H. Show the tracks of the particles in your diagram. (4 marks)



Q7.
(86)



The figure above shows the variation of count rate of a radioactive source measured by a GM counter with time.

(a) Find from the figure, the background count rate of the room. (2 marks)

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(b) Find the count rate due only to the radioactive source at time 0. (2 marks)

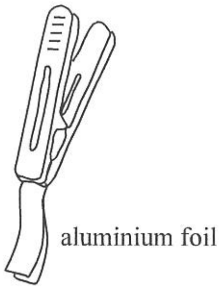
____

(c) Determine the half-life of the radioactive source. (2 marks)

____

____

Q8. The below figure shows a pair of positively charged aluminium foils.
(87)



(a) When the aluminium foils are placed near an α source, the foils are found to gradually collapse. Briefly explain why. (2 marks)

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____

(b) Would the foils collapse faster or slower if the foils were placed near a γ source instead of an α source ? Explain briefly. (2 marks)

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Q9. A student measures the count rate of a source of half-life of 25 min using a GM counter in a room with very little background
(89) radiation. Initially the reading of the GM counter shows 560 counts per second.

(a) What should be the count rate of the source after 25 minutes ? (2 marks)

____

____

(b) Plot on the graph below the theoretical decay curve of the radioactive source for the first 100 minutes. (4 marks)

(c) The actual readings of the GM counter are as follows:

Time / min.	0	50	75	100
Count rate / counts per second	560	154	70	31

Do you think that the GM counter is working properly ? Explain briefly. (3 marks)

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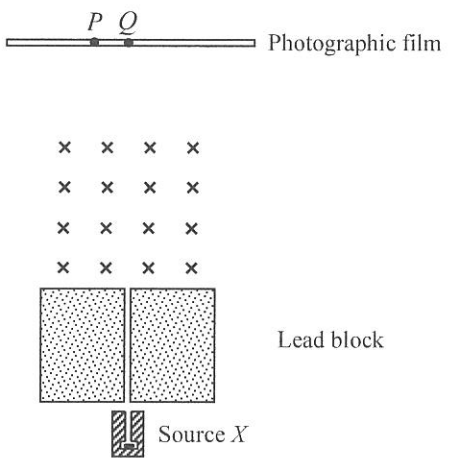
Q10. (a) What is the major source of background radiation
(89)
(i) at an altitude of 10000 m above sea-level ;
(ii) inside the Lion Rock Tunnel ;
(iii) in an underground coal mine ? (3 marks)

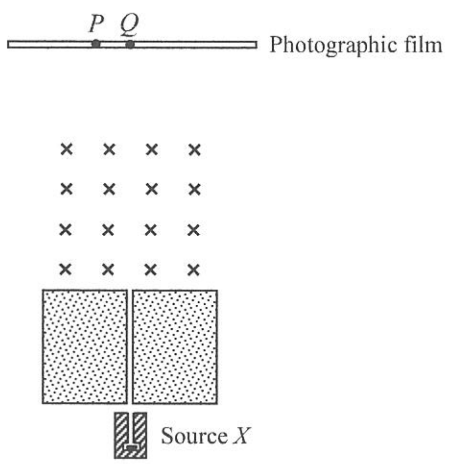
(b) It is reported that the background radiation in a concrete building is higher than that in a wooden hut. A person thus decides to move to a wooden hut. Do you think that his decision is wise ? Explain briefly. (3 marks)

Q11.
(90)



The above figure shows the set-up of an experiment carried out in an evacuated chamber to study the radiation from a radioactive source X. X emits α, β and γ radiation. A magnetic field (pointing into the paper) is applied. The photographic film is developed and marks in the positions P and Q are observed.

(a) In the figure below, sketch and label the paths of the α, β and γ radiation emitted from the source X. (5 marks)



Q11. (b) Explain briefly

(i) why the experiment is carried out in an evacuated chamber. (2 marks)

(ii) the use of the lead block in the set-up. (2 marks)

(c) If a piece of cardboard is placed between the source and the lead block, what type(s) of radiation would be recorded on the photographic film ? (2 marks)

(d) Suggest an alternative detector to replace the photographic film in the experiment. (2 marks)

Q12. A cloud chamber is used to observe the tracks of α-particles.
(93)

(a) Describe the tracks of α-particles in the cloud chamber. (2 marks)

(b) An α-particle collides with a helium nucleus to form a fork track. What is the angle of the fork track and what does this angle indicate ? (2 marks)

Q13. In a school laboratory, the background count rate recorded by a GM counter is 100 counts per minute.

(95) (a) The counter is placed close in front of a radioactive source *P*. The following results are obtained :

Time t / hour	0	20	40	60	80	100	120
Recorded count rate / counts per minute	620	400	270	199	157	133	118

(i) Find the corrected count rate at $t = 0$. (1 mark)

(ii) Plot the graph of the corrected count rate against time on the graph below. (5 marks)

(iii) Hence find the half-life of the source. (1 mark)

(b) To find out the kind(s) of radiation emitted by *P*, sheets of difference materials are placed in turn between *P* and the counter. The following results are obtained :

Material	Recorded count rate / counts per minute
–	620
Paper	623
5 mm Aluminium	98
5 mm Lead	101

Explain how the result shows that *P* emits β radiation only and it does not emit α or γ radiation. (4 marks)

Q13. (c) If the experiment in (b) is repeated with another source Q which emits both α and γ radiation, a different set of readings would be obtained, as shown in the below table.

Material	Recorded count rate / counts per minute
–	750
Paper	x
5 mm Aluminium	y
5 mm Lead	z

From the following list, choose suitable values for x, y and z :

0, 100, 195, 540, 750

(Note : A reading may be used more than once.) (3 marks)

Q14. (99) To investigate the kind(s) of radiation emitted by a radioactive source, a Geiger-Muller counter is placed close in front of the source and sheets of different absorbers are placed in turn between the source and the counter. Three readings are taken at one-minute intervals for each absorber. The following results are obtained :

Absorber	Recorded count rate / counts per minute		
	1st reading	2nd reading	3rd reading
–	700	710	693
Paper	702	703	701
1 mm Aluminium	313	320	317
5 mm Lead	98	101	100

The background count rate recorded by the counter is 100 counts per minute.

(a) Explain why the three readings for each absorber are not identical. (1 mark)

(b) Explain how the above results show that the source emits β radiation only and it does not emit α and γ radiation. (4 marks)

Q15.
(01)

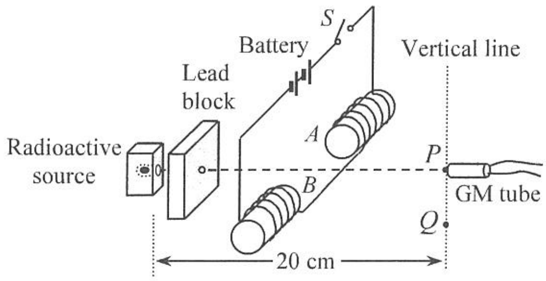


Figure 1

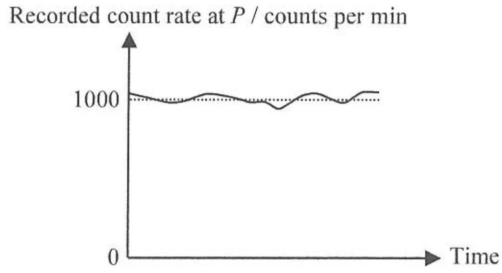


Figure 2

Figure 1 shows a set-up used to study the radiation from a radioactive source. A GM tube is placed at position P, which is at 20 cm from the source. Two coils A and B connected to a battery and a switch S are placed between the source and the GM tube as shown. Initially, S is open and the variation of the count rate recorded by the GM tube with time is shown in Figure 2.

(a) Explain why the count rate shown in Figure 2 is **not** due to α particles, no matter what kinds of radiation are emitted by the source. (2 marks)

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(b) Now switch S is closed. The GM tube is placed at positions P and Q in turn (see Figure 1) and the count rates recorded are shown in Figure 3 and 4 respectively. When the GM tube is placed at any point vertically above P, an average count rate of 100 counts per minute is recorded at each point.

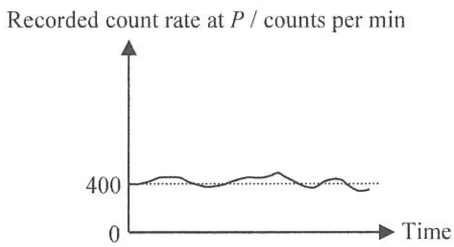

Figure 3

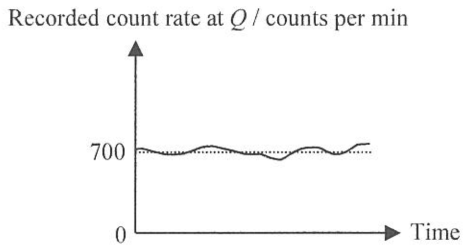

Figure 4

(i) State the direction of the magnetic field formed between coils A and B. (1 mark)

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(ii) What kind of radiation is recorded when the GM tube is held at any point vertically above P ? Explain your answer. (3 marks)

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(iii) What conclusion about the radiation emitted by the source can you draw from Figure 3 and Figure 4? Explain your answer. (4 marks)

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(iv) Explain why the sum of the average count rates recorded in Figure 3 and Figure 4 is greater than that recorded in Figure 2. (2 marks)

____

(c) The above experiment **cannot** determine whether α particles are emitted by the source. Suggest a method for finding out the answer. (2 marks)

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Q16. Carol performs an experiment to measure the half-life of a radioactive source. She places a Geiger-Muller tube in front of the
(05) source and the following results are obtained :

Time t / hour	0	10	20	30	40	50	60	70
Count rate / counts per minute	400	225	154	119	107	105	100	102

(a) Plot a graph of the count rate against time in the Figure below. (4 marks)

(b) Estimate the background count rate. (1 mark)

(c) Estimate the corrected count rate at $t = 0$. Hence, or otherwise, estimate the half-life of the source. (2 marks)

Q17. Workers of nuclear plants are required to wear film badges (see Figure 1) to monitor their exposure to radiation. Inside the
(06) film badge, an opaque plastic bag is wrapped around a sheet of photographic film. Aluminium and lead sheets are also placed inside the badge (see Figure 2) so that the types of incoming radiation can be distinguished.

Figure 1

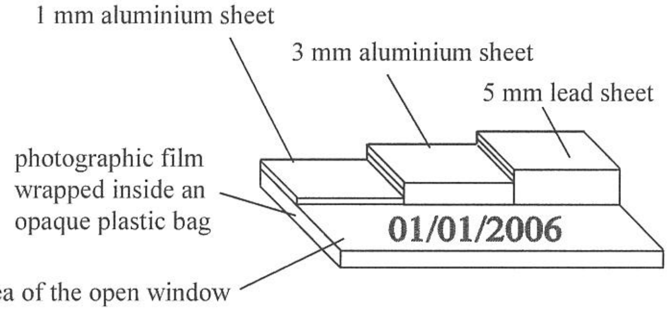


Figure 2

(a) What type(s) of radiation can be detected by the badge ? (1 mark)

(b) Why is an opaque plastic bag used to wrap the photographic film ? (1 mark)

(c) The films of three workers John, Mary and Ken were developed. The Table below shows the degrees of blackening on different regions of the films inside the badges which they wore.

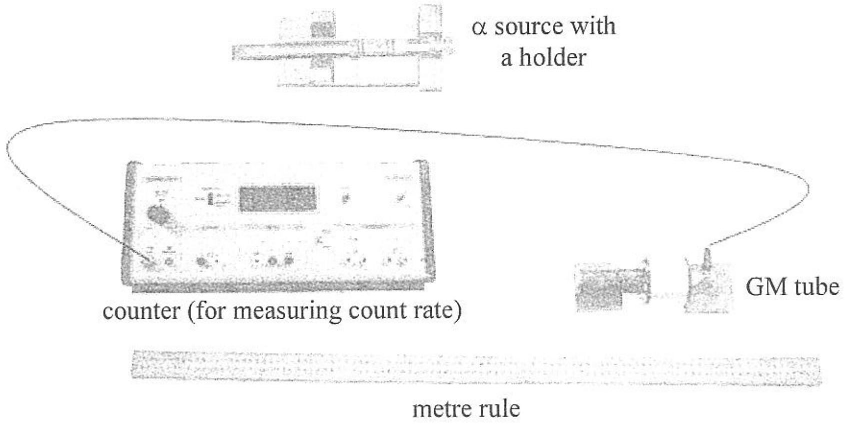
Regions on the film	Degree of blackening (0 – 5) (0 = not blackened; 5 = most blackened)		
	John	Mary	Ken
Beneath the open window	5	5	5
Beneath the 1 mm aluminium sheet	5	3	4
Beneath the 3 mm aluminium sheet	5	1	2
Beneath the 5 mm lead sheet	4	0	0

(i) Based on the results in the above Table, explain which type(s) of radiation John and Mary are definitely being exposed to respectively. (3 marks)

(ii) Give one reason why different degrees of blackening were recorded on the films of Mary and Ken. (1 mark)

(d) Suggest one hazard of exposure to ionizing radiations. (1 mark)

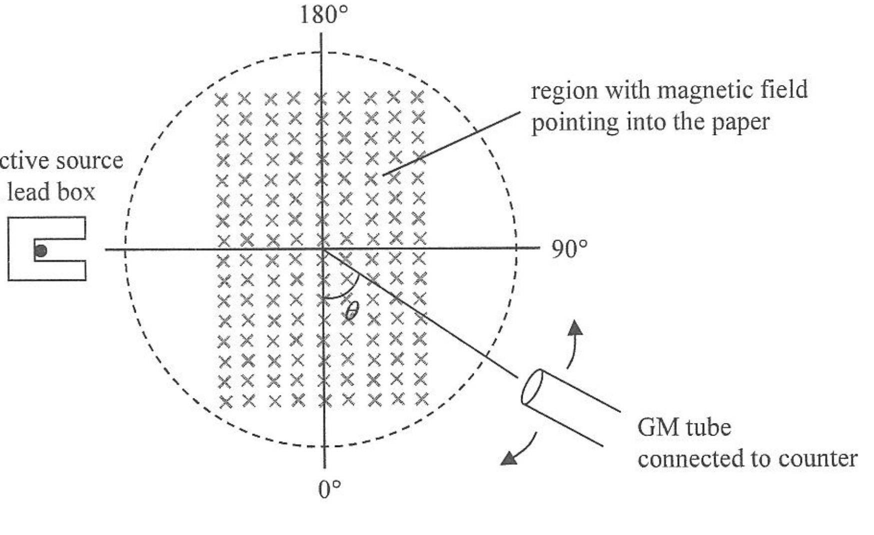
Q18. (07) In a physics lesson, a teacher uses the apparatus shown in Figure 13 to find the range of α particles in the air. Describe the procedures of the experiment. (4 marks)



Q19. (08) (a) A teacher places a radioactive source 1 cm in front of a Geiger-Muller tube (GM tube) and measures the count rate. When he inserts a piece of paper between the radioactive source and the GM tube, he finds that there is no significant change in the measured count rate. State the conclusion about the type of radiation emitted from the radioactive source. (1 mark)

The teacher then conducts another experiment to investigate the deflection of radiations inside a magnetic field as shown in Figure 1. The GM tube can be rotated from 0° to 180° around the magnetic field. Figure 2 shows the count rate recorded at different angles with or without the magnetic field.

Figure 1



Q19.

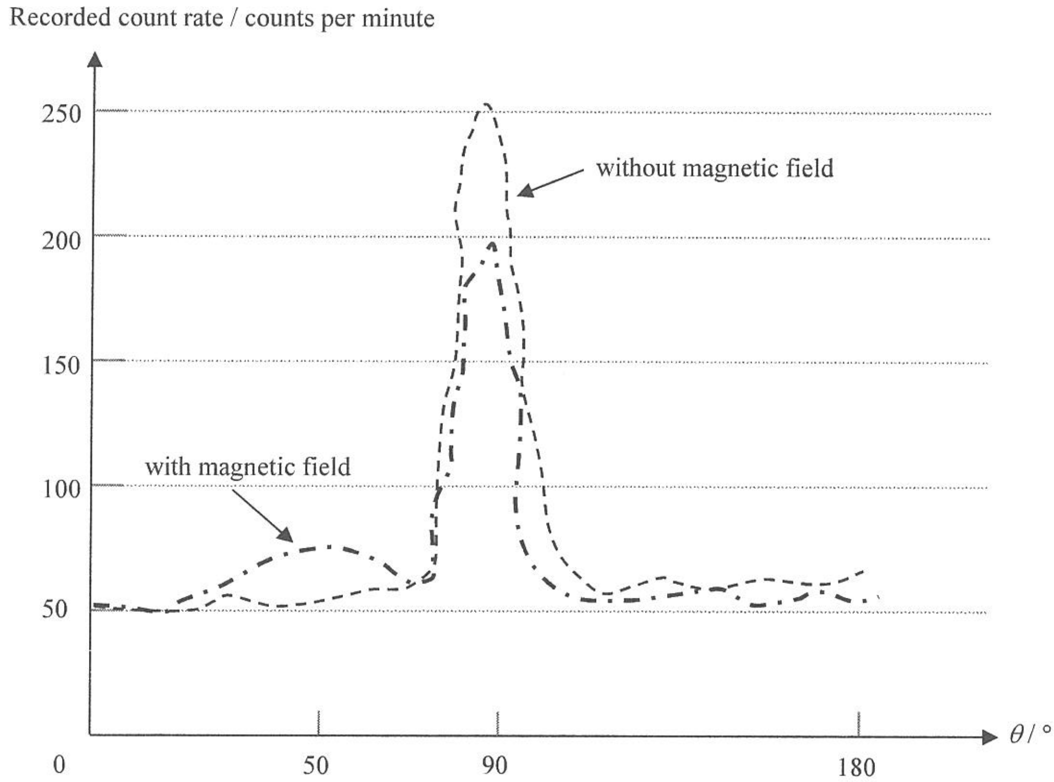


Figure 2

(b) Estimate the count rate due to the background radiation. (1 mark)

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(c) Using the result in Figure 2, explain why it can be concluded that the radioactive source emits β and γ rays. (4 marks)

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(d) Estimate the count rate due to each type of radiation at $\theta = 90°$ without the magnetic field. Write the answer in the Table below.

Type of radiation	Count rate / counts per minute
α	0
β	
γ	

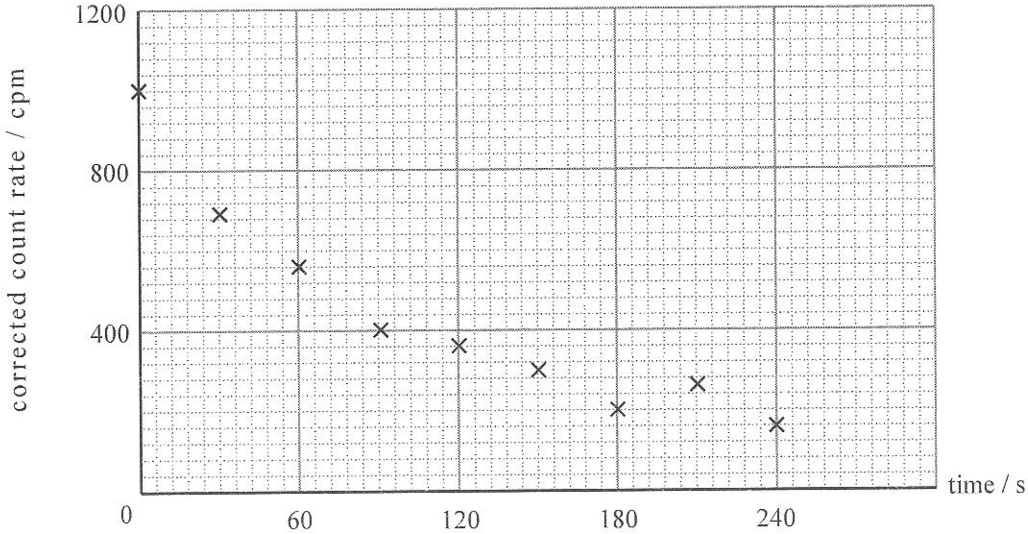
(2 marks)

Part C :

The following questions marked with [ ] are the past HKAL questions.

The number inside the brackets represents the year of the examination.

Q20.
[83]



The points plotted in the above Figure were obtained in an experiment to investigate the decay of the radioactive isotope protactinium-234 which decays by emitting β particles. Counts were taken in every 30 s interval by a GM tube and have been corrected by background radiation.

(a) A student comments that the readings have been taken carelessly because the points plotted in the above Figure do not fall on a smooth curve. Do you agree ? Explain your reasoning. (1 mark)

(b) Use the above Figure to estimate the half life of protactinium-234. (1 mark)

(c) Estimate the decay constant of protactinium-234. (1 mark)

(d) Express in words the relationship between the decay constant and the probability of an atom decaying. (1 mark)

Q21. [95] A geologist wants to find the age of a sample of rock containing potassium-40 which decays to give the stable isotope of Argon. The activity of the sample is found to be 1.6 Bq while the original activity of a similar rock having the same mass is 4.8 Bq. The half-life of potassium-40 is 1.3×10^9 years.

(a) (i) Find the decay constant of potassium-40. (2 marks)

(ii) Give the physical meaning of the decay constant of a radioactive isotope. (2 marks)

(b) Find the age of the rock sample. (2 marks)

(c) Give **two** factors that determine the activity of a radioactive source. (2 marks)

Q1. (a) Insert a piece of paper between the sample and the GM tube.

The count rate will remain approximately unchanged, showing that no α radiation is emitted. [1]

Insert a 5 mm aluminium plate between the sample and the GM tube. [1]

The count rate will drop to the background count rate level, showing that β radiation is emitted. [1]

(b) $k = \dfrac{\ln 2}{136} = 5.10 \times 10^{-3}\ \text{s}^{-1}$ [1]

(c) Initial corrected count rate $= 1000 - 50 = 950$ cpm

Final corrected count rate $= 250 - 50 = 200$ cpm [1]

By $C = C_o\, e^{-kt}$ **OR** By $C = C_o \left(\dfrac{1}{2}\right)^{t/t_{1/2}}$ [1]

$\therefore\ (200) = (950)\ e^{-5.10\times10^{-3}\,t}$ $\therefore\ (200) = (950)\left(\dfrac{1}{2}\right)^{t/136}$

$\therefore\ t = 306$ s $\therefore\ t = 306$ s [1]

Q2. (a) The penetrating power of α is so weak that it cannot pass through the thin metallic casing of the RTG. [1]

(b) (i) $k = \dfrac{\ln 2}{t_{1/2}} = \dfrac{\ln 2}{(87.74\times3.16\times10^{7})} = 2.50\times10^{-10}\ \text{s}^{-1}$ [1]

$A_o = kN = (2.50\times10^{-10})(3.2\times10^{25})$ [1]

$= 8.00\times10^{15}$ Bq [1]

(ii) $P = EA = (5.5\times10^{6}\times1.6\times10^{-19})(8\times10^{15})$ [1]

$= 7040$ W

$= 7.04$ kW [1]

(iii) As $P \propto A \propto N$

$\dfrac{P}{P_o} = \dfrac{A}{A_o} = e^{-(2.50\times10^{-10})\times(36\times3.16\times10^{7})} \times 100\% = 75.2\%$ [2]

OR

$\dfrac{P}{P_o} = \dfrac{A}{A_o} = \left(\dfrac{1}{2}\right)^{t/t_{1/2}} = \left(\dfrac{1}{2}\right)^{36/87.74} \times 100\% = 75.2\%$ [2]

< accept using the ratio of number of nuclei N > < accept 75% >

Q3. (a) Half-life of X = 4 min [1]

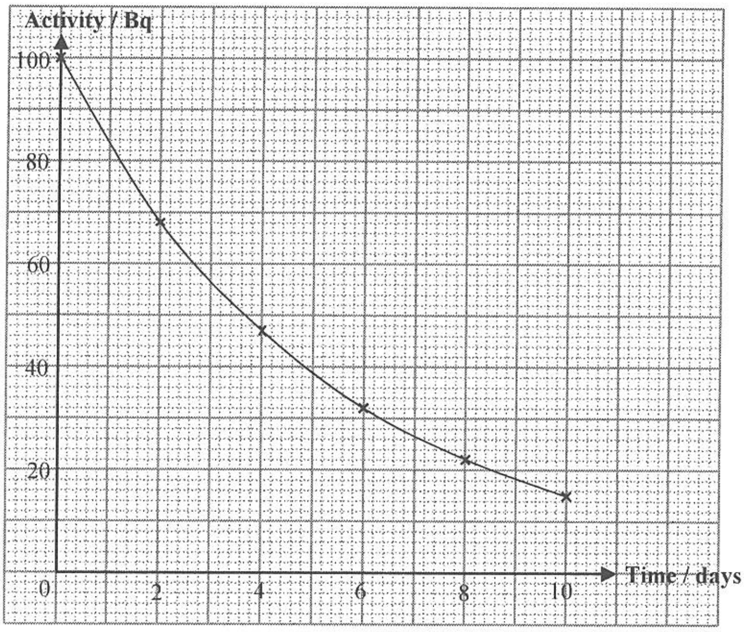
Half-life of Y = 32 min [1]

(b) X will be mainly be responsible for the reading [1]

Ratio of the number of counts due to X to that of Y = 0.5 : 0.08 [2]

Fraction of total number of counts due to X $= \dfrac{0.5}{0.5+0.08} = 0.862$ [2]

Q4. (a)



< Two axes correctly labeled > [1]

< Scales properly marked > [1]

< Points correctly plotted > [1]

< Curve correctly drawn > [1]

(b) (i) activity after 5 days = 39 Bq (± 1) [1]

(ii) half-life = 3.7 days (± 0.1 days) [1]

Q5. (a) There is background radiation. [1]

(b) It is due to the random nature of radiation. [2]

(c) β radiation only [1]

There is no α since α is stopped by paper. [1]

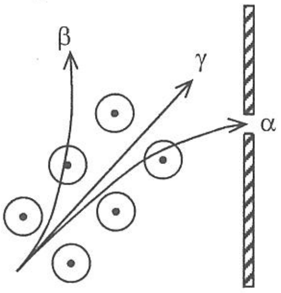
β is present since β is absorbed by aluminium and the count rate is reduced. [1]

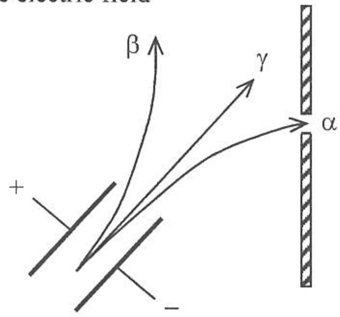
There is no γ since the count rate left is very small which should be due to background radiation. [1]

Q6. (a) The charge is positive. [1]

(b) (i) α particle [1]

(ii) Use magnetic field **OR** Use electric field [4]





Q7. (a) Background count rate = 40 counts per minute [2]

(b) Count rate at time 0 = 200 – 40 [1]

= 160 counts per minute [1]

(c) Half-life = 7 minutes < accept 6.5 minutes to 7.5 minutes > [2]

Q8. (a) The α particles ionize air. [1]

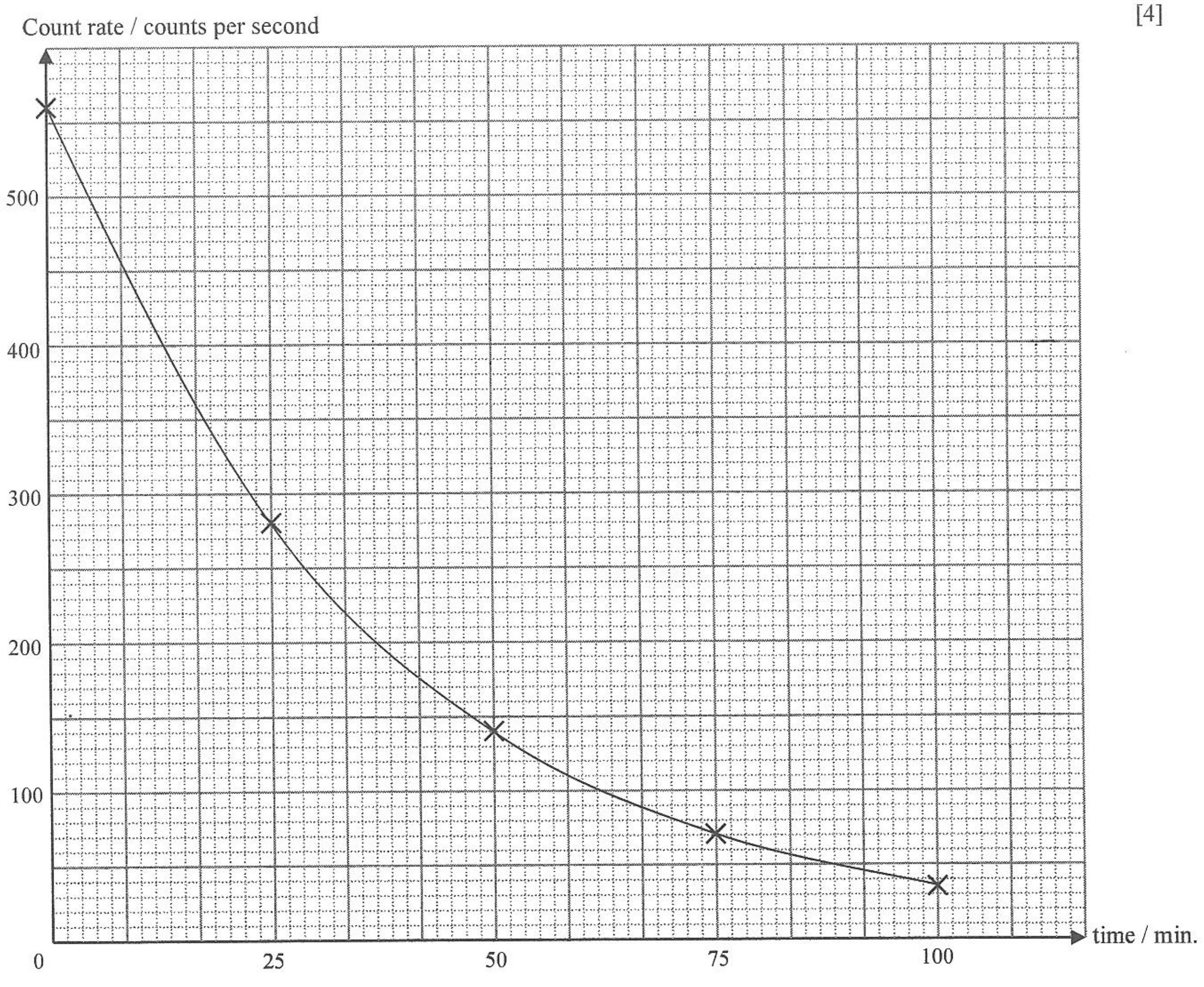
The ions then discharge the aluminium foils. [1]

(b) The foils would collapse slower [1]

since γ has weaker ionizing power [1]

Q9. (a) 280 counts per second [2]

(b) [4]



(c) Yes, the GM counter is working properly. [1]

The readings do not match the theoretical curve exactly due to the random nature of radiation. [2]

Q10. (a) (i) cosmic radiation from the outer space [1]

(ii) from the rock [1]

(iii) from the coal (or carbon) [1]

(b) Both Yes or No are acceptable but the reasons should be consistent. [1]

Reason for Yes : [2]

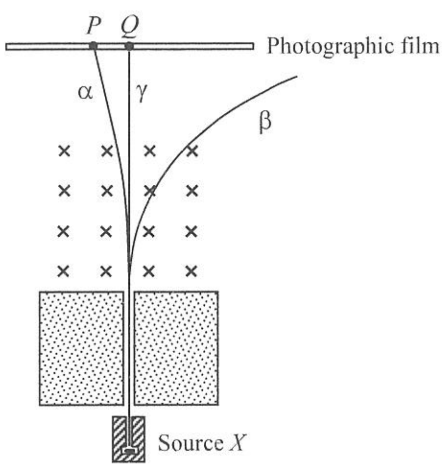
✻ The cumulative effect of radiation is harmful

Reason for No : (any ONE) [2]

✻ The background radiation in a concrete building is weak and not hazardous

✻ The chance of being harmed by other factors such as fire in a wooden hut is increased

Q11. (a)



< 2 rays reaching P, Q > [1]

< α radiation > [1]

< γ radiation > [1]

< β radiation – towards the right > [1]

< β radiation not reaching the film > [1]

(b) (i) α-particles have short range in air. [2]

(ii) To produce a fine beam of radiation [2]

(c) γ radiation only [2]

(d) GM tube [2]

Q12. (a) The tracks are (ANY TWO) : [2]

✻ straight

✻ thick

✻ short

✻ of about the same length

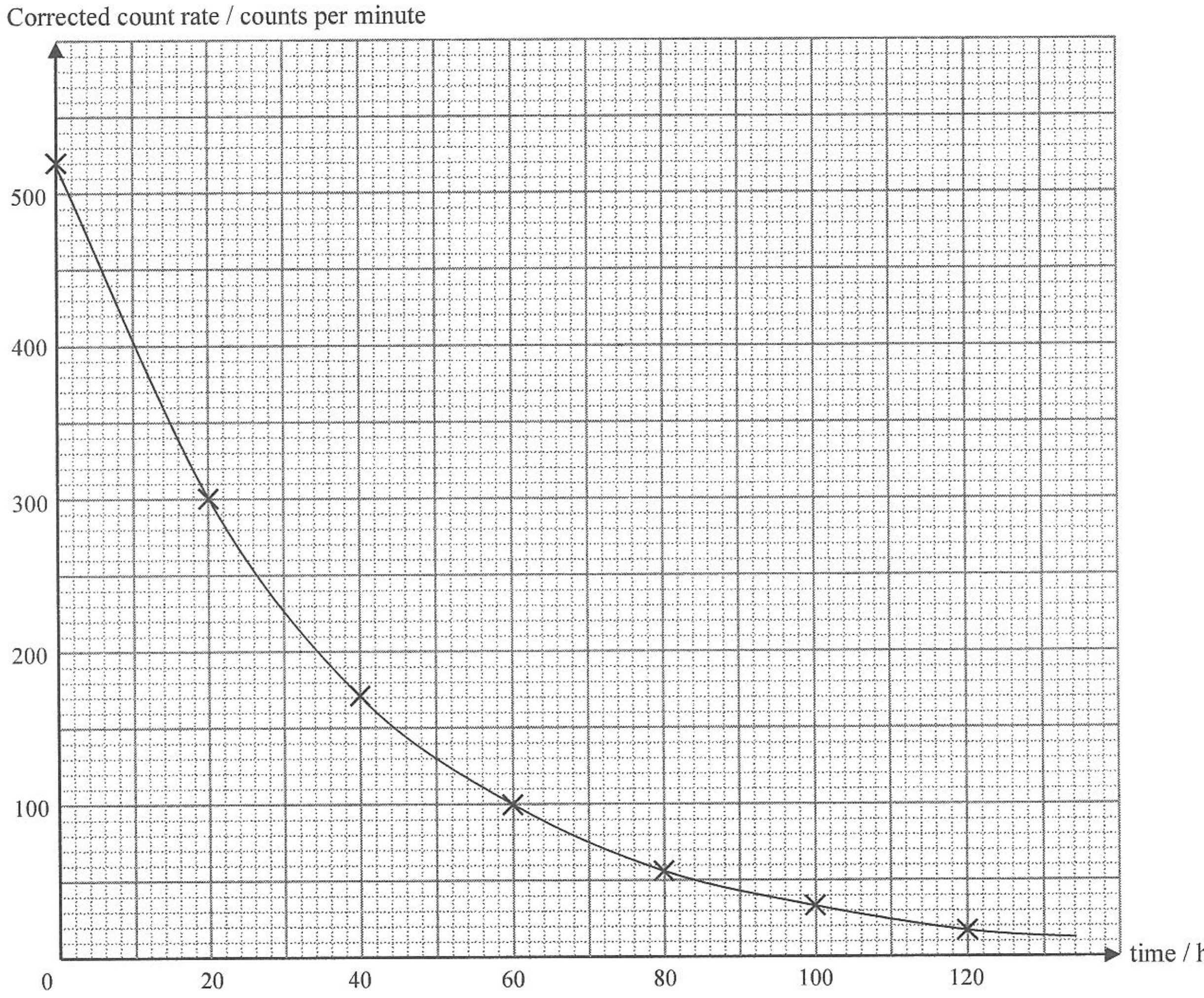
(b) The angle is 90° [1]

The masses of an α particle and a helium nucleus are the same. [1]

Q13. (a) (i) Corrected count rate = 520 counts per minute [1]

(ii) [1]

Time t / hour	0	20	40	60	80	100	120
Corrected count rate / counts per minute	520	300	170	99	57	33	18



< Correct label of the two axes with units > [1]

< An appropriate scale (not less than 1 cm to 50 c.p.m. and 1 cm to 10 hours) > [1]

< Correct points plotted > [1]

< Smooth curve drawn > [1]

(iii) From the graph, half-life = 25 hours < from 23 to 27 hours is acceptable > [1]

(b) The source does not emit α radiation

since the recorded count rate almost remains unchanged when a sheet of paper is inserted. [1]

The count rate drops significantly when aluminium is inserted, this illustrates that it emits β radiation. [1]

The source does not emit γ radiation

because the count rate recorded when 5 mm lead is inserted

is not different from that when aluminium is inserted. [2]

Q13. (b) **< Alternative solution >**

The source does not emit α radiation

since the recorded count rate almost remains unchanged when a sheet of paper is inserted. [1]

The count rate drops significantly when aluminium is inserted, this illustrates that it emits β radiation. [1]

The source does not emit γ radiation

because the count rate already drops to background rate when aluminium is inserted. [2]

(c) $x = 540$ [1]

$y = 540$ [1]

$z = 195$ [1]

Q14. (a) This is due to the random nature of radiation. [1]

(b) α radiation is stopped by a piece of paper.

β radiation is partially absorbed by 1 mm aluminium.

γ radiation is partially absorbed by 5 mm lead. [1]

As the count rates remain unchanged when a sheet of paper is inserted,

the source does not emit α radiation. [1]

As the count rates drop significantly when 1 mm aluminium sheet is inserted,

the source emits β radiation. [1]

As the count rates drop to background radiation when 5 mm lead is inserted,

the source does not emit γ radiation. [1]

Q15. (a) The range of α particles in air is only a few centimeters. [2]

(b) (i) The magnetic field is from B to A. [1]

(ii) The count rate is due to background radiation only. [1]

β or γ cannot be deflected upward. [2]

(iii) As the count rate at P and Q are greater than the background radiation, some radiations are detected. [1]

As the radiation detected at P is not deflected by the magnetic field, it must be γ radiation. [1]

As the radiation detected at Q is deflected downwards by the magnetic field, it must be β radiation. [1]

So the source emits β and γ radiation. [1]

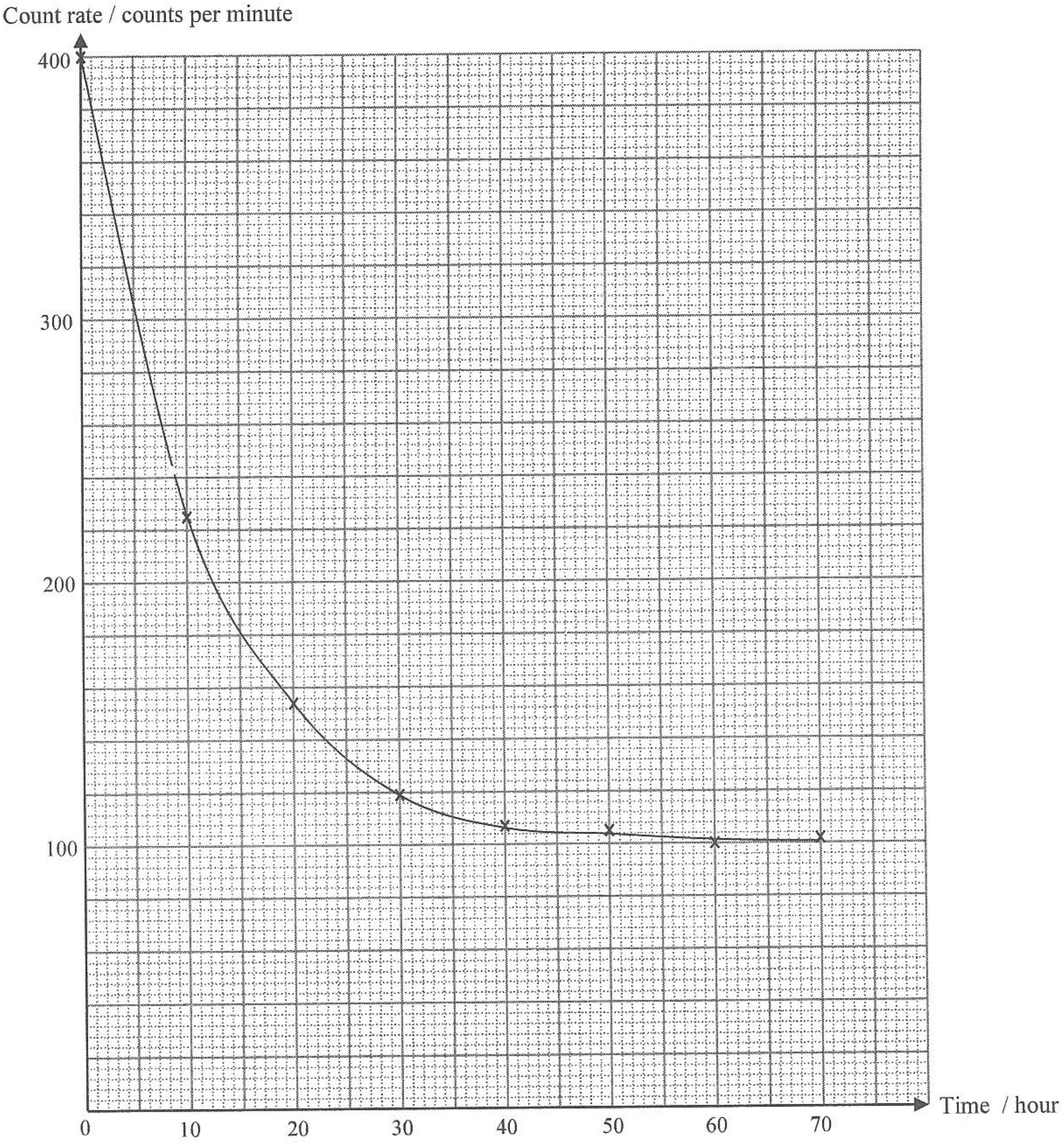
(iv) The background radiation is recorded at both Figure 3 and Figure 4, [1]

so the background radiation is counted twice and thus the sum is greater. [1]

(c) Place the GM tube close in front of the source. [1]

Insert a piece of paper in between. If the count rate drops significantly, α particles are emitted. [1]

Q16. (a)



< Two axes correctly labelled with units > [1]

< An appropriate scale > [1]

< Correct points (at least 7 points correct) > [1]

< A curve through the points > [1]

(b) The background count rate is 100 counts per minute. [1]

< from 95 to 105 is acceptable >

(c) The corrected count rate at $t = 0$ is 300 counts per minute. < from 295 to 305 is acceptable > [1]

The half-life is 8 hours. < from 7 to 9 hours is acceptable > [1]

Q17. (a) β radiation and γ radiation [1]

(b) To prevent light rays from entering the bag and blackening the film. [1]

Q17. (c) (i) John is exposed to γ radiation [1]
since γ can pass through the 5 mm lead sheet and blacken the film. [1]
Mary is exposed to β radiation since the film under the aluminium sheets is blackened but the film under the 5 mm lead sheet is not blackened. [1]

(ii) The radiation dose received by Ken is higher than that of Mary. [1]

(d) Any **ONE** of the following : [1]
- It can destroy living cells.
- It can cause cancer.
- It can cause the genetic change.

Q18. Place the α source close to and facing the GM tube. [1]

Increase their separation gradually and observe the count rate reading. [1]

Mark the point for the rapid drop in count rate. [1]

Measure the distance between α source and the GM tube with the metre rule to give the range. [1]

Q19. (a) No α radiation from the source. [1]

(b) 50 counts per minute (50 cpm) < accept 50 to 60 cpm > [1]

(c) With magnetic field, a peak of count rate appears at 50°. [1]
As β-particles are negatively charged, they deflect inside the magnetic field. [1]
With magnetic field, a peak of current still exists at 90°. [1]
As γ-ray does not have charge, it does not deflect inside the magnetic field. [1]

(d) β : 50 < accept 50 to 60 > [1]

γ : 150 < accept 140 to 160 > [1]

Q20. (a) No! It is due to the random nature of radiation. [1]

(b) Half life = 72 s < from 60 to 84 s is acceptable > [1]

(c) $k = \dfrac{\ln 2}{72} = 0.00963\ \text{s}^{-1}$ < from $0.00825\ \text{s}^{-1}$ to $0.0116\ \text{s}^{-1}$ are acceptable > [1]

(d) The decay constant is equal to the probability of decay of an atom per unit time. [1]

OR

The decay constant is equal to the probability of decay of an atom in 1 s. [1]

Q21. (a) (i) $k = \dfrac{\ln 2}{1.3\times10^9}$ < **OR** $\dfrac{\ln 2}{1.3\times10^9\times365\times24\times3600}$ > [1]

$= 5.33\times10^{-10}\ \text{year}^{-1}$ < **OR** $1.69\times10^{-17}\ \text{s}^{-1}$ > [1]

(ii) The decay constant of a radioactive isotope is the probability of decay of the nuclei present [1]
per unit time. [1]

(b) $\because$ $A = A_0\, e^{-kt}$

$\therefore$ $(1.6) = (4.8)\, e^{-5.33\times10^{-10}\,t}$ < **OR** $(1.6) = (4.8)\, e^{-1.69\times10^{-17}\,t}$ > [1]

$\therefore$ $t = 2.06\times10^9$ years < **OR** $t = 6.50\times10^{16}$ s > [1]

(c) ① The number of undecayed nuclei present [1]

② The decay constant of the radioactive source < **OR** The half-life of the radioactive source > [1]

GCE AL Physics (Edexel) course

C.W.Sham

Unit 1 : Physics on the go

1.1 Mechanics

1.2 Material

Unit 2 : Physics at work

2.1 Waves

2.2 DC Electricity

2.3 Nature of light

Unit 4 : Physics on the move

4.1 Further Mechanics

4.2 Electric Field

4.3 Magnetic field

4.4 Particle Physics

Unit 5 : Physics from creation to collapse

5.1 Thermal energy

5.2 Nuclear energy

5.3 Oscillation

5.4 Astrophysics and cosmology

* 沈sir錄了一套英國 GCE AL 的課程，放在 VIP，供有需要的同學報讀。
* 這課程是專為有意往外國升讀大學的同學而設。
* 全套課程只有四個單元(unit)。
* 每單元只有四堂，每堂約一小時四十五分至二小時。
* 讀完單元一 (unit 1)及單元二 (unit 2)，相等於完成英國中六的物理課程。
* 讀完單元四 (unit 4)及單元五 (unit 5)，相等於完成英國中七的物理課程。
* 筆記全英文，上課語言是廣東話。
* 每一單元的考試可以獨立報考和重考，直至獲得滿意成績。
* 單元三 (unit 3)是考核單元一及二的實驗卷。
* 單元六 (unit 6)是考核單元四及五的實驗卷。
* 考獲單元一至三的合格成績，報讀美國四年制大學，等同中六 AS 程度。
* 考獲單元一至六的合格成績，報讀英國三年制大學，等同中七 AL 程度。